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Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

ADVANCED TECHNOLOGY DISCUSSION DOCUMENT

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and
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ENERGY RESEARCH PROGRAM
COAL RESEARCH LABORATORIES
CANMET REPORT ERP/CRL 86-65 (TR)

MICROMEDIA

ADVANCED TECHNOLOGY DISCUSSION DOCUMENT

by

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ABSTRACT

This report presents a programme of applied research to be carried out by the Advanced Technology Section of the Surface Mining Laboratory of the Coal Research Laboratories (CRL), CANMET. The thrust of the programme is on near-term (0-5 years) with emphasis on co-operative research relating to evaluation, enhancement and application mining technologies which have a direct and tangible bearing on production costs.

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RAPPORT D'ÉTUDE SUR LA TECHNOLOGIE DE POINTE

par

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RÉSUMÉ

Ce rapport présente un programme de recherches appliquées qui sera entrepris par la Section de la technologie de pointe du Laboratoire d'exploitation minière à ciel ouvert des Laboratoires de recherche sur le charbon (LRC), CANMET. Ce programme à court-terme (0-5 ans) mettra l'emphase sur une recherche menée en coopération dont l'objet sera l'évaluation, la valorisation et l'application des techniques minières qui ont un effet direct et tangible sur les coûts de production.

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INTRODUCTION

During the past year the situation in the Coal and Oilsands industry has dramatically changed - for the worse. The trailing world-wide economic recession and a glut of oil on the world's market has totally changed the supply-demand patterns putting heavy pressure on the coal and oilsands producers to control and reduce cost of production. Abundant supply of liquid fuel at a price which is currently 50% of that a year ago is forcing coal producers and exporters to accept lower prices and a reduction in contracted volumes. There have been periodic shut-downs at mines resulting in intermittent and permanent lay-offs.

Given this scene it is imperative to protect Canadian interests - particularly in the export market of coal. Canadian price and costs must be maintained at a competitive level to other coal producing countries exporting coal to the same markets as Canadians do. Recognise the fact that in 1985 Canada produced approximately 60 x 10^6 tonnes of coal of which some 27 million tonnes were exported almost all of it from British Columbia and Alberta. Western Canada provides 95% of the total Canadian production - the bulk of it by surface mining methods.

The mandate of the Advance Technology Section of Coal Research Laboratories is to undertake technical studies relating to mining technologies which have a direct and tangible bearing on production costs.

This section will be responsible for undertaking investigations of new potentially attractive surface mining technologies which will result in improvement of overall system productivity, resource recovery and safety and will, as a minimum, be cost competitive with the methods they will either replace and/or augment. Existing mining techniques will be reviewed to identify improvements where possible. Demonstration projects relating to new mining systems - mining methods and equipment will be undertaken. Information resulting from such endeavours will be disseminated in a timely manner by organizing technology transfer forums.

PROPOSED RESEARCH PLAN

This proposal presents a tentative five year plan of applied co-operative research and is based on the assumption that external resources equal to that provided by CANMET-CRL will be available. The CANMET-CRL resources committed to this activity are two person-years and approximately $200,000 p.a. in addition to staff salaries and overheads.

The proposed activity is divided into four sub-heads-namely

- Enhancement of current surface mining methods
- Innovative techniques - application of micro-processor based technology and emerging mining methods
- Economic and operational strategies
- Technology Transfer

A brief description of each activity follows:

IDENTIFICATION AND ENHANCEMENT OF CURRENT SURFACE MINING METHODS

A prime activity in surface mining is that of materials handling: disposing ore and waste in a systematic and cost-effective manner. Canadian coal and oil sands mines are highly mechanized and use a variety of material excavation equipment. The operating costs of such equipment are generally more than half of the total operating costs of a mine. To control costs, therefore, optimal selection and proper field use of this equipment is vital.

A discussion on the applicability of different types of equipment and some of the recent developments is given in a CANMET technical report entitled "Equipment Selection and Utilization in Surface Mining".

This report was especially written for this briefing document and is given in appendix I. Two other recent reports entitled "Steep Seam Coal Mining in Western Canada By Open Pit Mining" and "Productivity and Equipment Selection in Surface Mining of Oil Sands" also included in Appendix I, review the surface mining methods as used in western Canadian coal and oil sands operations.

Combined together these documents cover the whole spectrum of existing and in some cases proposed western Canadian surface mining technology and illustrate typical outputs of this project.

It is proposed that during the next five years three specific subjects be studied. These are:

- Selective Mining
- Alternative Methods of Mining Deeper Overburden to supplement a Dragline
- Haul Road Design, Construction and Maintenance.

Selective Mining

Scrapers, front-end loaders, draglines, bucketwheels, and hydraulic shovels all have been used for selective mining. The machine chosen in a particular situation depends on site-specific conditions mostly relating to the geology of the seam. Given the same geology - different type and size of equipment will result in varying degrees of resource recovery and costs. As such a formal study is warranted to provide guidelines for optimal selection of equipment for selective mining.

In multiple seam mining where seams are separated by thin bands of overburden (interburden); in cases where coal seams are split and where materials of different qualities must be separated, application of a new breed of mining equipment called surface miners is available (Fig 1). Such machines can mine to very narrow limits improving resource recovery and providing an uncontaminated product. By separating materials of various qualities at the source considerable savings in downstream processing and blending can be realized.

Many types of surface miners are commercially available. The OBED MOUNTAIN COAL COMPANY LTD. owns an Easi-Miner. More recently a German machine Wirtgen 3012SM miner has been field tested at the Luscar-Bienfait mine in Saskatchewan. The machine was used to cut and load the hard sandstone interburden.

It is proposed to carry out studies identifying suitable mining methods and equipment capable of mining selectively. The thrust of the project will be in evaluating the alternatives available and to highlight in each case, the associated economics.

Alternative Methods of Mining Deeper Overburden to Supplement a Dragline

The Canadian coal and oilsands mining industries use some 30 draglines with a bucket capacity of 30 yd^3 or over. This is a sizeable capacity.

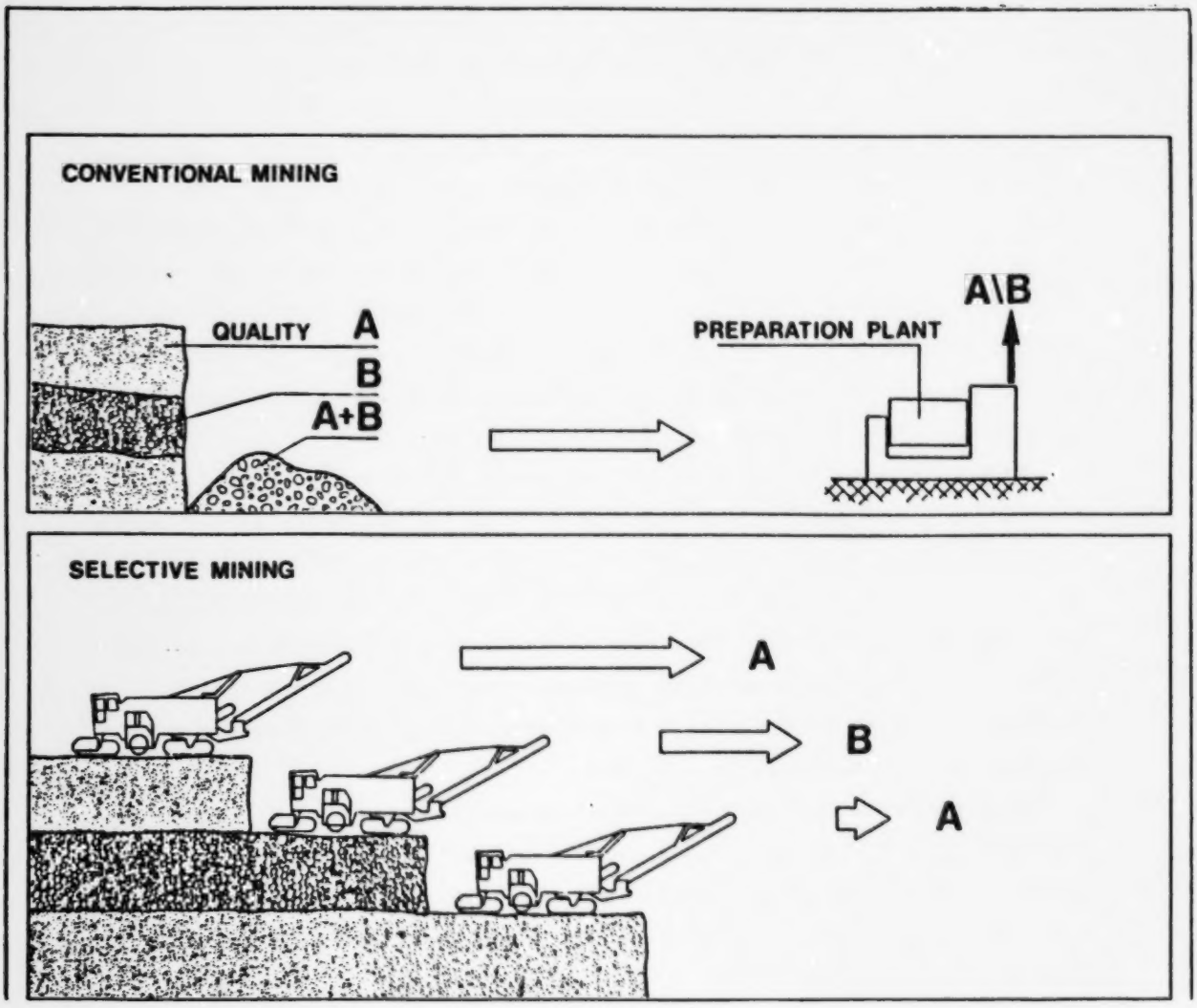

Fig. 1 Selective mining permitting Separation of quality product at source

Proper use of draglines to lower cost of material handling and to minimise rehandling is necessary. One major factor which significantly affects dragline production is their use in chop-cutting. Draglines are designed to dig below grade and their use in chop cutting should be avoided. Chop cutting always results in reduced productivity sometimes by as much as 50% compared with the normal operating mode of a dragline. (Table 1)

When sizing a dragline an allowance must be made for an unanticipated increase in depth of overburden particularly where highwall stability is a problem. This, in turn, generally calls for an allowance in the sized length of the dragline boom. For overburden depths of greater than 45m a supplemental pre-stripping system should be considered to support a dragline.

It is proposed to carry out studies identifying suitable pre-stripping system to supplement dragline operations. Application of such systems will invariably result in changes to a mine plan. The thrust of the project will be in evaluating the alternatives available and to highlight, in each case, the economic and physical constraints imposed in mine planning and implementing a proposed plan.

Haul Road Design, Construction and Maintenance

In Canadian surface mines, trucks provide a significant and proven mode of material transportation. They are available in various sizes from a number of manufacturers. The truck-productivity depends upon a number of factors - some relating to the equipment itself and others relating to the environment in which it operates. The most significant, external factor affecting truck productivity is the condition of the surface on which it travels - the haul road. Trafficability, a 'catch-all' term used to describe haul road condition, is greatly influenced by the rolling resistance.

The rolling resistance (R.R) is the amount of drawbar pull or tractive effort required to overcome the retarding effect between the tires and the ground. It is a result of tire penetration, tire flexing and internal power train friction. Additional resistance is encountered when a machine travels upgrade. This resistance called - grade resistance (G.R.) is defined as the drawbar pull or tractive effort required to overcome gravity in propelling a vehicle up an incline.

Total resistance is the sum of rolling and grade resistances.

In practical terms, the influence of rolling resistance is best illustrated by an example. In this case a fleet of 85t trucks is sized using Caterpillar's VEHSIM program. Five million tonnes of overburden are to be transported to a fixed dumping site along a specified haul route. The only variable in this exercise is the rolling resistance which varies from 4% to 16% in four equal steps. The output from the VEHSIM program is summarized in Table 2. Comparing the performace data for 4% R.R. with that for 16% R.R. it is noted that

- the hourly production at 16% R.R. is approximately 53% of that obtained at 4% R.R.
- the number of trucks required at 16% R R is twice the number required at 4% R.R.
- annual operating cost of the truck fleet at 16% R.R. is approximately twice that of 4% R.R.

This example clearly demonstrates that haul road rolling resistance can have a significant effect on mine production.

It is proposed to carry out studies relating to the design and construction of haul roads with a view to reduce rolling resistance and improve trafficability. The Surface Mining Laboratory has equipment under development to rapidly monitor the rolling resistance. Areas to be investigated are: sub-surface materials used in the construction of haul-roads; use of soil-binders; and geotextiles to improve trafficability by enhancing soil properties and drainage.

The intent is to provide data to permit mine operators to assess the economic implications of enhancing haul road trafficability by trading off increased haulroad construction costs with reduced truck haulage operating costs.

INNOVATIVE TECHNIQUES: APPLICATION OF MICRO-PROCESSOR BASED TECHNOLOGY AND EMERGING METHODS

We are entering a new era of the an electronic age! It is no exaggeration to state that micro-processors and computers will be increasingly used in all facets of mining (some other industries e.g. manufacturing and transportation are well ahead in the use and adaptation of this technology). On one hand this technology will bring reliabilty,

Table 1. Dragline production estimate showing reduction in volume handled due to chopdown

	30'	ESTIMATED BENCH OPERATIONS	
		120' DEPTH	
	Chopdown Cut	Bank 100° Swing	Rehandle 90° Swing
Bucket Size	80 c.y.	80 c.y.	80 c.y.
Material Swell Factor	.76	.76	.90
Fill Factor	.80	.85	.90
Overall Bucket Factor	.61	.65	.81
Bank cubic yards/bucket	49	52	65
Estimated Cycle Time			
Load and Drag	16 sec.	13 sec.	12 sec.
Hoist and Swing	29	18	23
Return Swing	27	17	16
Basic Cycle Time	72 sec.	48 sec.	51 sec.
Cycle per 50min/hr.	42	63	59
Annual Available Hours	8,760	8,760	8,760
Less time not Scheduled	760	760	760
Average Number of 60 minute hours	8,000	8,000	8,000
Discount Factor for Operating Delays	.80	.80	.80
Effective No. of 60 minute/hour	6,400	6,400	6,400
Production Available Per Hr. (bcy)	2,058	3,276	3,835
Production Available Per Year (bcy)	13.17×10^6	20.97×10^6	24.54×10^6

Table 2. Influence of rolling resistance on off-highway truck performace in an oil sands surface mine (according to caterpillar tractor co. vehicle simulation program).

Truck : Carterpillar 777 Empty Weight : 129820 Lb
Payload : 1700000 Lb Tires : 27x49
Haul Road Grade : 7%

Haulroad Specifications		Production Estimation vs. Rolling Resistance (%)				
Segment No.	Distance (Ft.)		4%	8%	12%	16%
1	500	Fixed Time (Min.)	1.5	1.5	1.5	1.5
2	1500	Haul Time (Min.)	17.75	25.25	32.98	39.34
3	1000	Return Time (Min.)	6.32	6.32	6.34	7.25
4	1400	Cycle Time (Min.)	25.56	33.07	40.83	48.09
5	3500	Trips/60 min. Hour	2.35	1.81	1.47	1.25
6	4150	Payload (TONS)	85	85	85	85
		Production (TONS) /60 min HR	199.47	154.22	124.92	106.04
		Annual Production/ Truck (4818HR) X 10^3 TONS	961	743	602	511
		Annual Production (X 10^3 TONS)	5000	5000	5000	5000
		Number of trucks needed	5	7	8	10
		Capital Required (X 10^3 \$)($700,000 per truck)	3500	4900	5600	7000
		Truck Operating Hours (Production 5000 X 10^3 TONS)	25064	32421	40026	47152
		Annual Fleet Operating Cost ($60/HR) (\$ X10^3)	1503	1945	2402	2829

dependability and flexibility to mining systems and processes. On the other they will result in a lowering of production costs largely by a reduction in manpower.

With the advent of micro-processor technology various types of equipment performance as well as health and safety monitoring systems for surface mining equipment have become available. Typical examples are: suspended load measurement modules for electric cable shovels and draglines measuring and quantifying cycle times, production per cycle/truck, overload/underload analysis, accumulated production; on-vehicle weighing instrumentation; on-board health monitoring and equipment operating environment analysis, anti-collision technology (radar transponder system, close-in sonar and infrared sensors etc.); built-in safety features in the equipment (improved mirrors; fresnel lenses and collision warning electronics); drilling efficiency indicators mounted on blast hole machines giving rate of penetration, depth drilled, distance from bottom, accumulated depth etc.; boomsentry anti-tightline control system designed to protect dragline booms from structural damage caused by either excessive mechanical loading or by bucket swing etc.

This equipment monitoring instrumentation is capable of gathering and analyzing "real time" data on equipment operations, its performance and will give advance warning of impending failures in machine components thus enabling improvements to be made in equipment deployment and maintenance.

Canadian surface mines recognize the benefits of this technology and are beginning to accept it. Such equipment has already been installed in some draglines, bucketwheels, shovels etc.

The Advance Technology Section will:

- aim to highlight the technical and economical benefits of this technology by keeping abreast of world-wide developments,
- aim to introduce this technology into Canadian surface mines,and
- propose, as applicable, modifications to the off-the-shelf technology to make it more acceptable in the harsh Canadian climate.

New Mining Methods

Geology of a deposit plays an important part in the selection of mining equipment and the applicable mining method(s).

During the next few years it is visualized that there will be no major departures from current practices. Equipment as used at present will continue to be used, however it will be more micro-processor controlled, will have on-board computers and its construction will be more modular to enable easier erection, dismantling, and maintenance.

Developments in four distinct areas are expected to be attractive to the mining industry:

a) selective mining methods based on the application of surface miner, C-miner and road header type of machines equipped with infra-red sensors to monitor quality of mined product.

b) Greater application of conveyor technology: - the development and availability of portable and mobile conveyors is adding flexibility to such systems opening up new areas for their application. Truck haulage is highly labour intensive and high in operating costs. It is considered that application of such conveyors will result in appreciable reduction in material handling costs.

With the application of such systems a 100 person crew operating and maintaining a truck fleet can be replaced by a 10 person crew to handle the equivalent amount of material on conveyors. Whereas truck fleet manpower is directly related to the volume handled - conveyors are not affected. Only one conveyor operator is required whether the conveyor is 36" wide or 72" handling four times as much material. Remote and automatic control of conveyor systems is available. In contrast automatic truck dispatch systems must still be considered under development; automatic truck control to replace truck drivers, although tried, is not available.

Application of mobile and portable crushers and feeder breakers has further broadened the scope of conveyor transportation enabling many mine materials handling systems to bridge the gap between a true continuous mining system (BWE/conveyor) and a totally discontinuous mining system. (Fig.2).

The application of high angle conveyor technology, the successful development of which took nearly forty years, will open up entirely new concepts in mine planning and scheduling, and will result in substantial reduction in material handling costs. A discussion on the application of these conveyors is given in the CANMET-CRL Report No. 86-66(TR) included in appendix I.

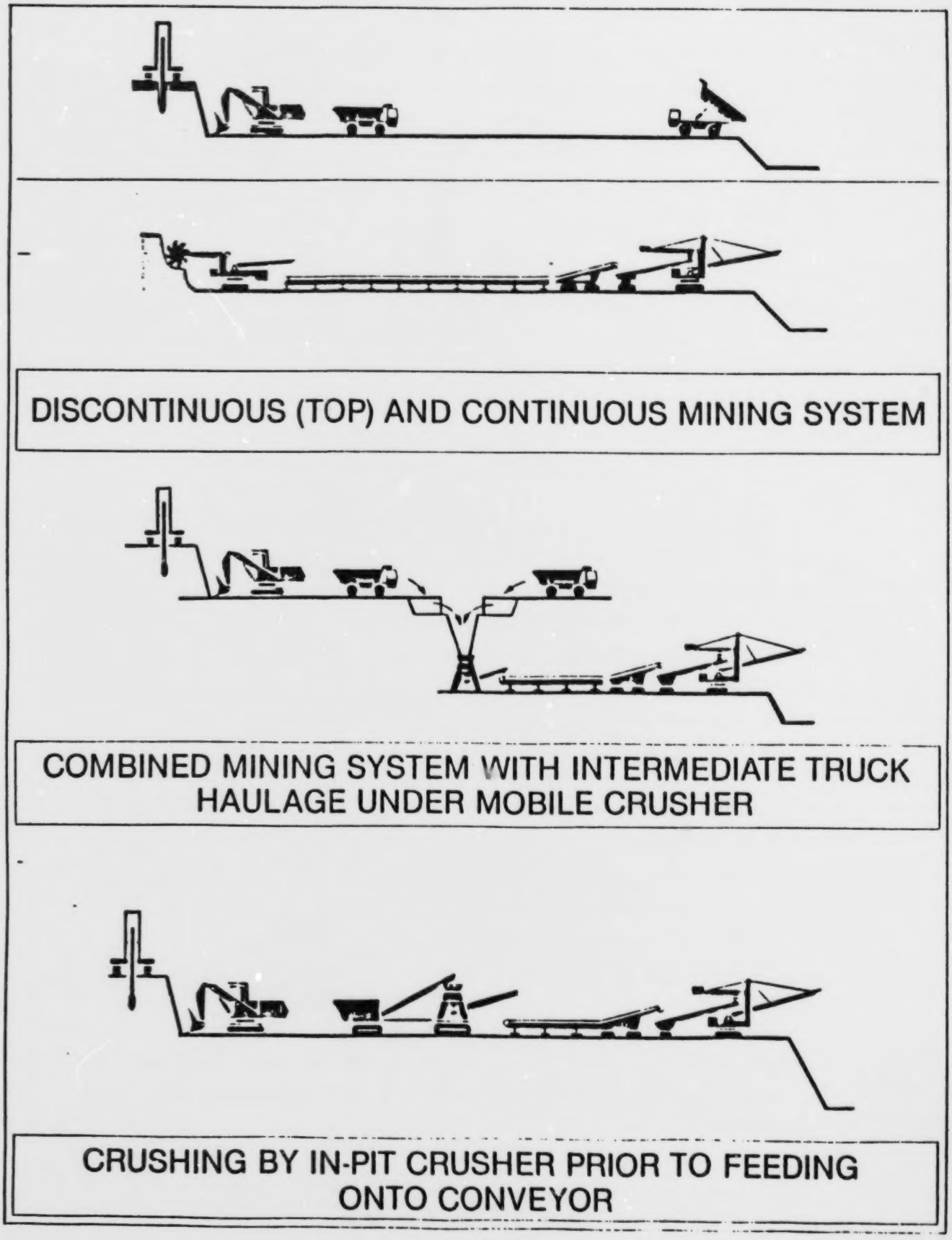
DISCONTINUOUS (TOP) AND CONTINUOUS MINING SYSTEM
COMBINED MINING SYSTEM WITH INTERMEDIATE TRUCK HAULAGE UNDER MOBILE CRUSHER
CRUSHING BY IN-PIT CRUSHER PRIOR TO FEEDING ONTO CONVEYOR

Fig. 2 Discountinuous, continuous and combined mining systems

(c) Each surface mine has an "optimum depth" determined at the time of technical and economic evaluation with on a set of given and estimated parameters. In some situations once the optimum depth has been reached it might be possible to successfully introduce underground mining using the surface mine infrastructure, already in place, for transportation.

There are also situations where underground transportation systems can be used in a surface mine from its inception. Such systems will be particularly useful where a tunnel could be excavated into the pit and used for rapid material movement on continuous systems such as conveyors. In mountainous terrain such systems are visualized to take advantage of gravity. The material will be dumped to lower elevation through an ore pass and transported from the lower level by conveyors.

Recognize that the geology and topography are two main factors which govern the applicability and success of such systems.

(d) In terms of the application of modified technology in Canadian mines explosive casting of overburden, continuous mining with heavy duty all-hydraulic compact bucket wheel excavators and the application of light and heavy duty mobile spreaders to waste disposal are seen to have sufficient potential to warrant preliminary studies to begin in the very near future.

Larger equipment has resulted in cost reduction in overburden handling; however as of now the surface mining equipment in terms of size has reached a plateau. Therefore to obtain further cost reductions new techniques for the removal of overburden should be devised. With the development of high strength explosives a method termed explosive casting has been developed. In this method explosives are used for the purpose of moving overburden as well as fragmenting it.

Where applicable the advantages of explosive casting are:

- up to 35 - 40 per cent of overburden may be moved directly on to spoil pile without the use of stripping equipment thus increasing the stripping capacity by a similar figure.
- the increased fragmentation resulting from the heavy blasting produces faster and easier stripping with less downtime and longer equipment life.

- in dragline operations, double handling of overburden can be eliminated by operating the dragline from the "heap" created by the shot. If good results are obtained from explosive casting this heap will be located far enough from the highwall so that no overburden will have to be handled twice.

CANMET-CRL consider this method to have potential in Canadian mines and have therefore recently proposed a field study to be undertaken with an industry partner. That study is expected to be completed within the next 12 months.

Such co-operative demonstration projects are difficult to fund with the current climate of intensive fiscal restraint. The Laboratory believes that such an approach is however necessary to produce "made in Canada" experience with potentially attractive techniques and technologies. Strong industry support is an essential prerequisite to such an approach.

In the area of new mining methods the Advance Technology section will:

- aim to highlight the technical and economic benefits of conveyor transportation technology including the development and application of mobile, semi-mobile and portable equipment as applied in surface mining,
- aim to promote this technology into Canadian surface mines by undertaking co-operative research and development projects with the industry, and
- aim to analyse and promote attractive alternative mining methods by highlighting economics and applicability in the Canadian context.

ECONOMIC AND OPERATIONAL STRATEGIES

More than one mining method with more than one type of equipment can be successfully used to mine the same mineral deposit. Consequently to arrive at an "optimum" mine plan all possible alternatives must be examined. The decision whether a particular method should be used or not will be based on its comparative economic index. One such index commonly applied is the discounted rate of return on capital invested for each scheme/project.

This evaluation is a highly complex process and must not be regarded as merely a "number-crunching" exercise. Considerable judgement is required and many interdisciplinary studies must be carried out and integrated to give a complete picture.

Cash flow to a project can be favourably "controlled" by strategically controlling the operating costs. For example by reducing haul distances in the short term haulage costs can be reduced thus increasing cashflow in a certain period. Thus in mine planning and scheduling optimum location of waste and ore stockpiles, the haul roads in and out of the pit, the processing plant etc. comprise a very significant consideration.

Even with the same type of equipment a variety of mine plans (methods) can be created-for example should an access ramp in the pit be along the footwall or hangingwall? Resolution of this question which seemingly is so straight forward requires a thorough investigation on the drawing board and could easily constitute one month's work for a mine planning engineer.

Reference to optimum depth has already been made. Optimum production rate is another item to be considered.

The Advance Technology section will:

- foster the knowledge relating to compatibility of mining geology, mining equipment, mining methods and mine planning and the influence of operational strategies on operating costs of a mine, and
- develop easy to understand procedures for "optimum" location of mine infrastructure (waste dumps, tailings pond, haul roads, maintenance shops etc.)

TECHNOLOGY TRANSFER

It is recognized that economic growth is due largely to increased productivity and that the rate of productivity growth depends on the rate of technological change. Technological change results from research and development (R&D). In order to fully utilize the benefits of R&D it is vital that there should be a systematic and timely dissemination of research findings. There are many ways in which dissemination of information can take place - all falling under the broad title "technology transfer".

The Surface Mining Laboratory have taken considerable initiative in this area by organizing symposiums in which representatives from industry, universities and federal and provincial agencies have participated fully.

For example, last year (1985) a two-day symposium on Mining Equipment Selection was organized at Calgary. Participants (176) heard and discussed reports on the full gamut of equipment development, selection and utilization. Twenty-eight papers were presented by authors from Canada, U.S.A., U.K., Sweden and the Federal Republic of Germany offering a broad perspective on the best efforts of industry, university, consultants, private and government researchers to meet the challenges of selecting optimal equipment.

A lateral thrust of this symposium was to highlighting the application of continuous mining systems. Such systems are already in use in Canada on large volume surface mineable oil sands projects.

This year (1986) Surface Mining Laboratory is involved in two symposiums. The theme of Continuous Mining Systems is taken up in a symposium organized jointly with the University of Alberta. This symposium will be held in Edmonton from September 29 - October 1, 1986.

The second symposium on Geotechnical Stability in Surface Mining, organized with the University of Calgary covers the broader role of geotechnical engineering in surface mining of coal, oilsands and metalliferous deposits and will be held in Calgary, November 6-7, 1986.

Short courses and seminars on diverse topics will be initiated by the Surface Mining Laboratory. Presenters will be drawn from the laboratory, industry and academia. Industry assistance will be required to identify promising topics.

The Advance Technology section will:

- work closely with industry to identify knowledge-gaps and promote collaborative R&D to fill these gaps,
- generate state-of-the-art and extended studies on Canadian and foreign operations on technology judged to have potential in Canadian surface mines, and
- attempt to transfer technology to industry relating to technology deemed to have potential in Canadian surface mines.

CONCLUDING REMARKS

In this document a pragmatic programme of applied research has been proposed. Its successful completion will lead to improved economics of surface mining operations. Planning is an on-going process and bearing in mind the thrust of the CANMET-CRL's work, which is to meet industry needs, active industry participation is invited to formulate a firm work-plan.

The development of this document alone is not enough. There must be durable mechnanisms in place to implement the work-plan. It is here where once again the mining industry can play an active role by supporting and sharing in the resources required to implement the proposed plan as well as in the benefits accruing from this work.

APPENDIX I

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EQUIPMENT SELECTION AND UTILIZATION IN SURFACE MINING

R.K. Singhal
Calgary Coal Research Laboratory

April 1986

Energy Research Program
Coal Research Laboratories
Division Report ERP/CRL 86-66(TR)

EQUIPMENT SELECTION AND UTILIZATION IN SURFACE MINING

BY

R.K. SINGHAL

ABSTRACT

This report reviews some of the equipment and systems used on a major scale for loading and transportation in surface mining with emphasis on procedures for equipment selection.

Scraper, front-end loaders and shovels are the mainstay of surface mining industry for loading. Trucks are used extensively for transporation. Conveyors are currently in use for out-of-pit long-haul transportation. However recent developments in conveyor transportation technology has enhanced their portability and mobility such that they are finding acceptance in in-pit transportation. New developments such as hydraulic bucketwheels, high angle conveyors and application of micro-processor based monitoring technology are also described.

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INTRODUCTION

In surface mining equipment operating costs are generally more than half of total operating costs. To control costs, therefore optimal selection of equipment is vital. Proper equipment selection and utilization can often make the difference between a profitable mining operation and a failure or at best a marginal operation. Main considerations in primary equipment selection are the geology of the deposit, production requirement, project life, capital availability, operating cost, geotechnical parameters and resource recovery. In simple terms the factors which influence equipment selection, sizing and utilization are given in Fig (1). Of these, the terms of reference and site specific parameters are the most important.

A wide variety of equipment is used for material excavation in surface mining including scrapers, electric cable shovels, front-end loaders, hydraulic shovels, draglines and bucketwheels. Various types of haulage trucks, conveyors, scrapers, trains and pipelines are used for transporting the excavated material.

SCRAPERS/FRONT END LOADERS/SHOVELS

Scraper, front-end loaders and electric cable shovels comprise the traditional loading equipment for surface mining industry.

Many types of scrapers are available. They are highly mobile machines, capable of selective mining and have an excellent weight to horse power ratio. They can climb grades approaching 45° and are most productive in softer materials. Scrapers are used for maintaining pit roads, digging ditches, general clean up work around the pit and for blending on stockpiles. Fig. 2 provides a capability chart for each type of scraper. Table illustrates the range of application of various types of scrapers.

Diesel powered front end loaders are highly mobile machines and capable of giving high production in good blasted rock. Front end loaders are being increasingly used a s load and carry machines performing both the excavation and face haulage functions. A typical example is the application where a front-end loaders(s) excavates from a pit bank and hauls the meterial to hopper or hopper/crusher for placement of the material on a conveyor system. Another system worth mentioning is the situation where front-end loaders are used in the staggered tandem and chain loadig system (Fig.3).

Electric cable shovels generally have low operating and maintenance costs, can handle coarse materials and are very robust machines with a life span of 20 to 30 years. Their main drawback is low mobility. They are also limited by steep grades, have limited selective mining capability and require support equipment e.g. dozer or wheel loader.

A newer development combining the operating merits of a shovel and a front-end loader is the hydraulic shovel. Most of the hydraulic shovels

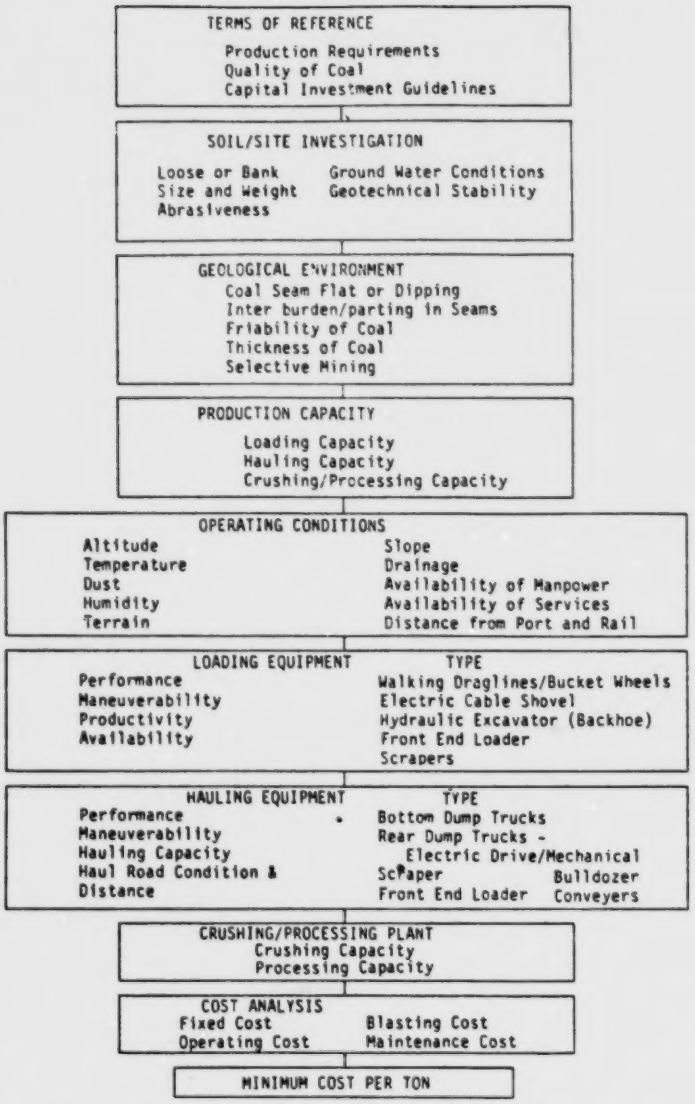


Fig 1. FLOW CHART - Mine Equipment Selection

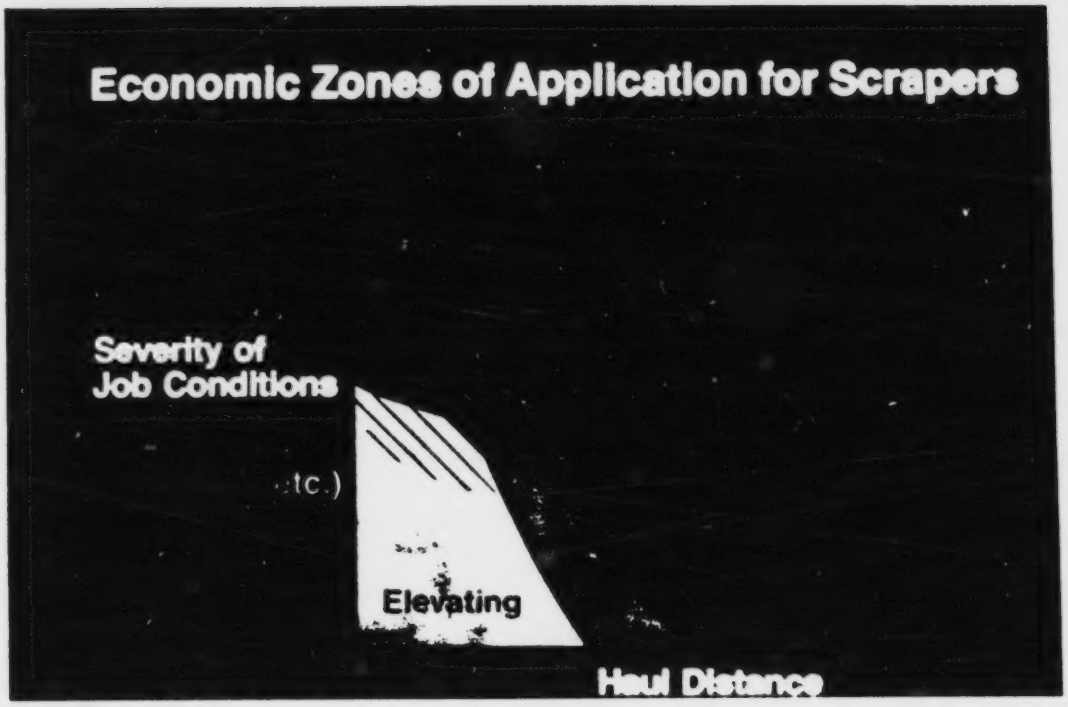


Fig 2. Economic zones of application for scraper-compatibility chart

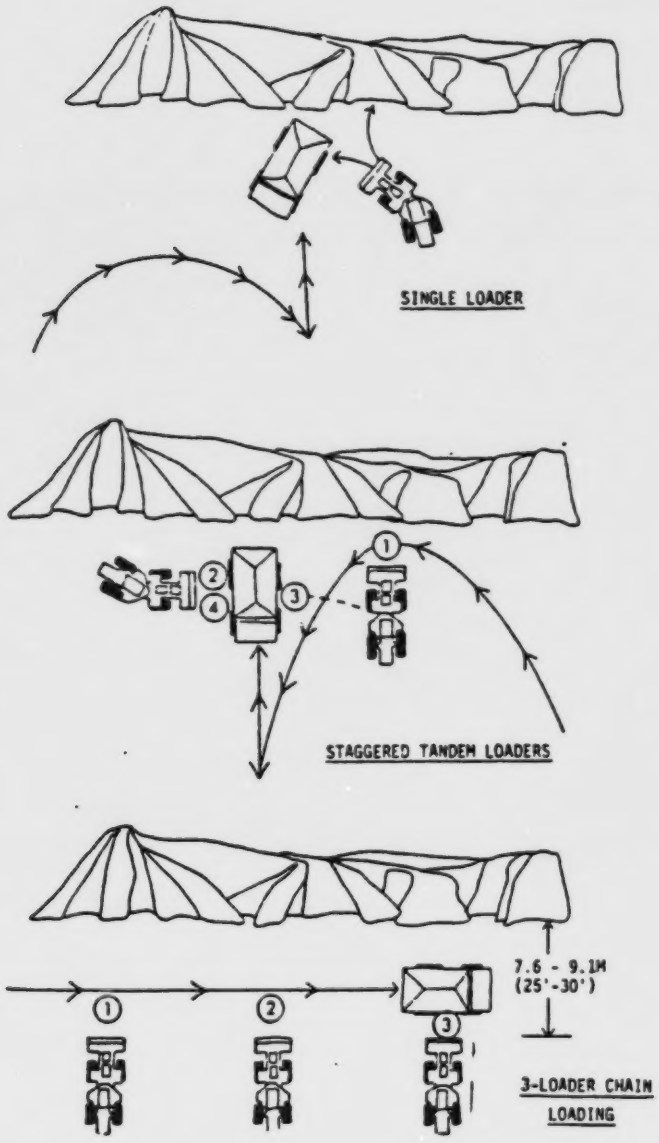


Fig 3. STAGGERED TANDEM AND CHAIN LOADING FOR FRONT END LOADER/TRUCK SYSTEM

Table 1.

Factors to Consider in Scraper Selection

Conventional Scraper	Tandem Powered Scraper	Elevating Scraper	Push-Pull Scraper
Type of Material			
1) has the widest range of application due to a pusher.	1) range slightly less than that of conventional scrapers—tire costs can be higher	1) not advised beyond gravel because of high tire wear and elevator mechanism cost	1) most limited due to tire cost but range can be increased when push loaded
Grade Resistance, Rolling Resistance (RR) and Haul Distance			
2) economical.	2) economical in situations where its high cost is offset by its greater horse power and increased tractive effort.	2) most economical for short hauls—600 m on low rolling resistance and low grades	2) most flexible—can work in all areas where tandem powered scraper can work, can handle short hauls, high RR, etc., must have 75-m cut areas as minimum.
3) can climb grades of 25% empty and 15% loaded. Suitable for level and moderate grades on good haul roads.	3) can climb grades approaching 45%. Can also work in wet weather or in poor underfoot conditions, unlike single engine scrapers	3) can work alone, does not need a pusher and thus not vulnerable to mis-match. Often used to supplement conventional scrapers.	3) newest type where two modified tandem powered scrapers are placed in line and temporarily connected for loading. Needs no pusher, so no scraper/pusher mismatch, no bunching.
4) excellent all-around scraper.	4) excellent where a low weight to horse power ratio is needed.	4) elevator mechanism conditions the materials for better dumping and spreading.	4) extremely flexible machine.

available are diesel powered. A recent important trend, however, is to use electric power instead of diesel. This option has advantages in situations where the machine is being used as a main production unit, not requiring frequent moves. An electrically operated machine has lover operating cost and is not so noisy.

Table (2) provides a comparison of operating characteristics of a front end loader, electric cable shovel and a hydraulic shovel.

The hydraulic shovel has proved very effective in selective mining. The wrist action of this type of machine allows for efficient separation of waste from ore and reduces the downstream cost of screening and processing When converted to a backhoe the shovel can be used to mine inclined and folded seams. The units greater breakout force makes them ideal for loading compacted materials. (Figs 4 & 5).

In many situations the hydraulic shovel has replaced the conventional shovel and front-end loaders. Hydraulic shovels were once actively used with a bucket size of up to $20m^3$. Now they are competing with other loading equipment with bucket capacities of the $30m^3$ range. O&Ks hydraulic shovel RH300 is the largest machine available with a bucket of $34m^3$.

From Table (3) it is clear that for a similar size of bucket the weight of a hydraulic shovel is approximately one half that of a cable shovel. It has a speed of travel nearly twice that of cable shovels. The service life of flat shoe tracks is greatly reduced when power shovels travel for long distances. By comparison, hydraulic loading shovels are generally mounted on crawlers similar to those of heavy-duty bulldozers and their mobility is about that of a bulldozer - with a traveling speed of about 2.0 km/hr.

Table 3. Conventional Cable shovel VS. Hydraulic shovel ($23m^3$ bucket)

	Cable Shovel	Hydraulic Shovel
Drive Power (kW)	1450	1570
Ground Pressure (N/CM^2)	26	14
Travel Speed (km/hr)	1.16	2.10
Bucket Volume (m^3)	23	23
Operating weight (t)	885	485

Hydraulic shovels are versatile (Fig 6,7,8). With bullclam buckets, they are used for stripping overburden and mining ore in hard and soft rock

Table 2.

Comparison of Operating Characteristics of Hydraulic Shovel, Electric Cable Shovel and Front End Loader

Hydraulic Shovel	Electric Cable Shovel	Front-End Loader
Powerful digging force permits the machine to operate in a variety of conditions	A proven reliable and low operating cost machine available with bucket capacities of 50m³	A versatile machine highly mobile capable of speeds of up to 45km/hr can be used as primary loaders clean up traffic load and haul machine and as a dozer
To operate with an equivalent capacity bucket it requires roughly half the hoist and crowd needed by an electric cable shovel	Owing to the rigid stick and bucket design no wrist action is possible—a disadvantage in unblasted toes	Are being increasingly used as load haul-dump machines
It can dig above and below the floor level can be used as a back hoe	Its digging path approximates a quadrant of an ellipse with a vertical major axis The bucket digs the material throughout most of the digging cycle mining of thin bands and selective mining is not of forte of this machine	Lack of stability and traction problems result in higher loading cycle Staggered tandem and chain loading methods overcome some of the cycle time limitations
Effective application of digging forces results in low weight bucket size ratio For a similar size of bucket its weight is roughly half that of a cable shovel	Its digging action requires that material be dug from a horizon of approximately the same as the machine is working at Cannot dig below the working level	Bucket is designed to be wider than the width over the front tires in order to protect tires The width per unit capacity of this machine is higher than for other excavators
It's speed of travel is approximately double that of a cable shovel	It cannot traverse gradients greater than 1 in 20	Tire replacements costs contribute substantially to operating and maintenance costs
The horizontal crowd and wrist action permits loading of thin seams, compacted materials and unblasted materials and unblasted toes	With the shovels mechanism of discharging its bucket load no control over the dump rate is possible	Not suitable for soft ground cannot dig below grade drives forward to excavate and could result in severe damage to undercarriage
The machine is very effective in selective mining	Has a long life 20-30 years and low operating costs compared with either a hydraulic shovel or a front-end loader	Operates while moving so danger of overturning or falling over edge
Rate of material discharge from the bucket can be controlled to reduce impact load on truck pans		Ideally suited as a loader for well fragmented ground on good working surface Also used in face [illegible] clean up in the pit and to [illegible]
Excavates while standing in fixed position Soft ground has little effect on its capability		

Fig 4. Demag hydraulic shovel at Westar Mine

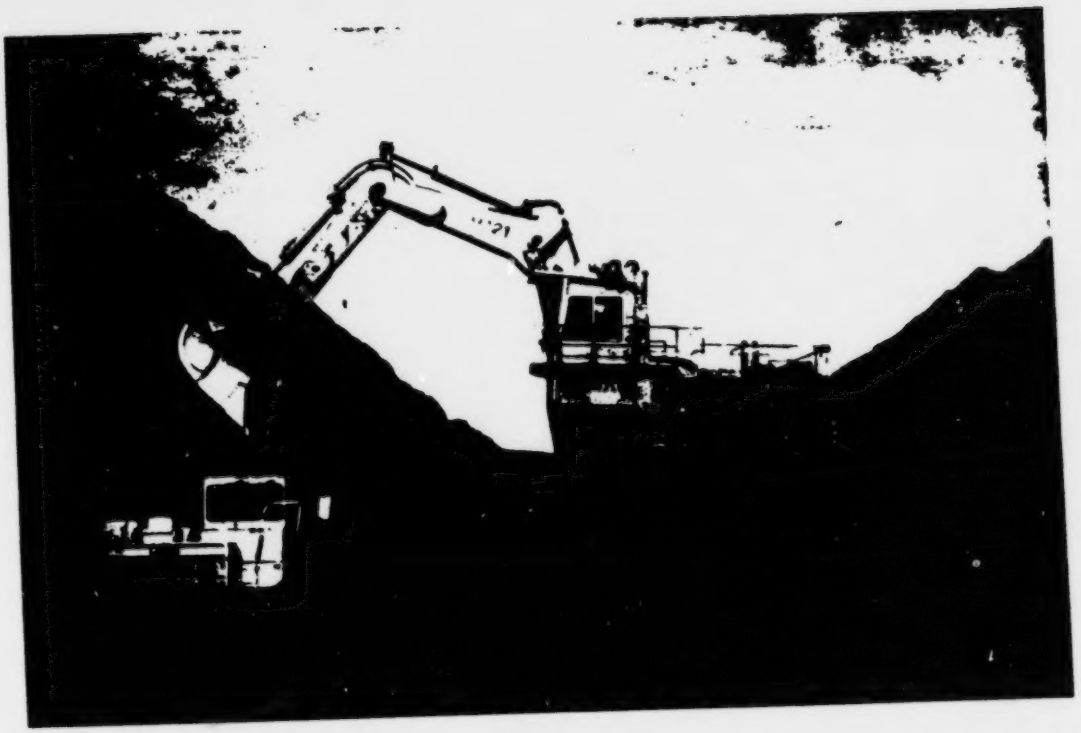


Fig 5. Hydraulic shovel used as a backhoe

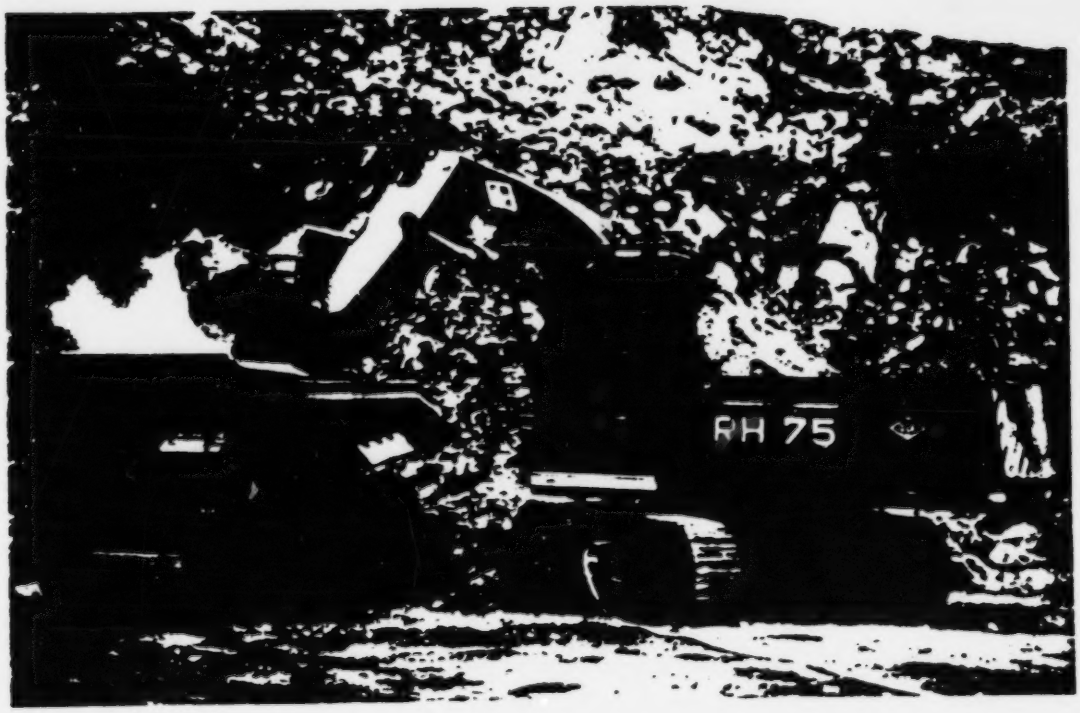


Fig 6. Hydraulic shovel digging hard rock at a copper Mine

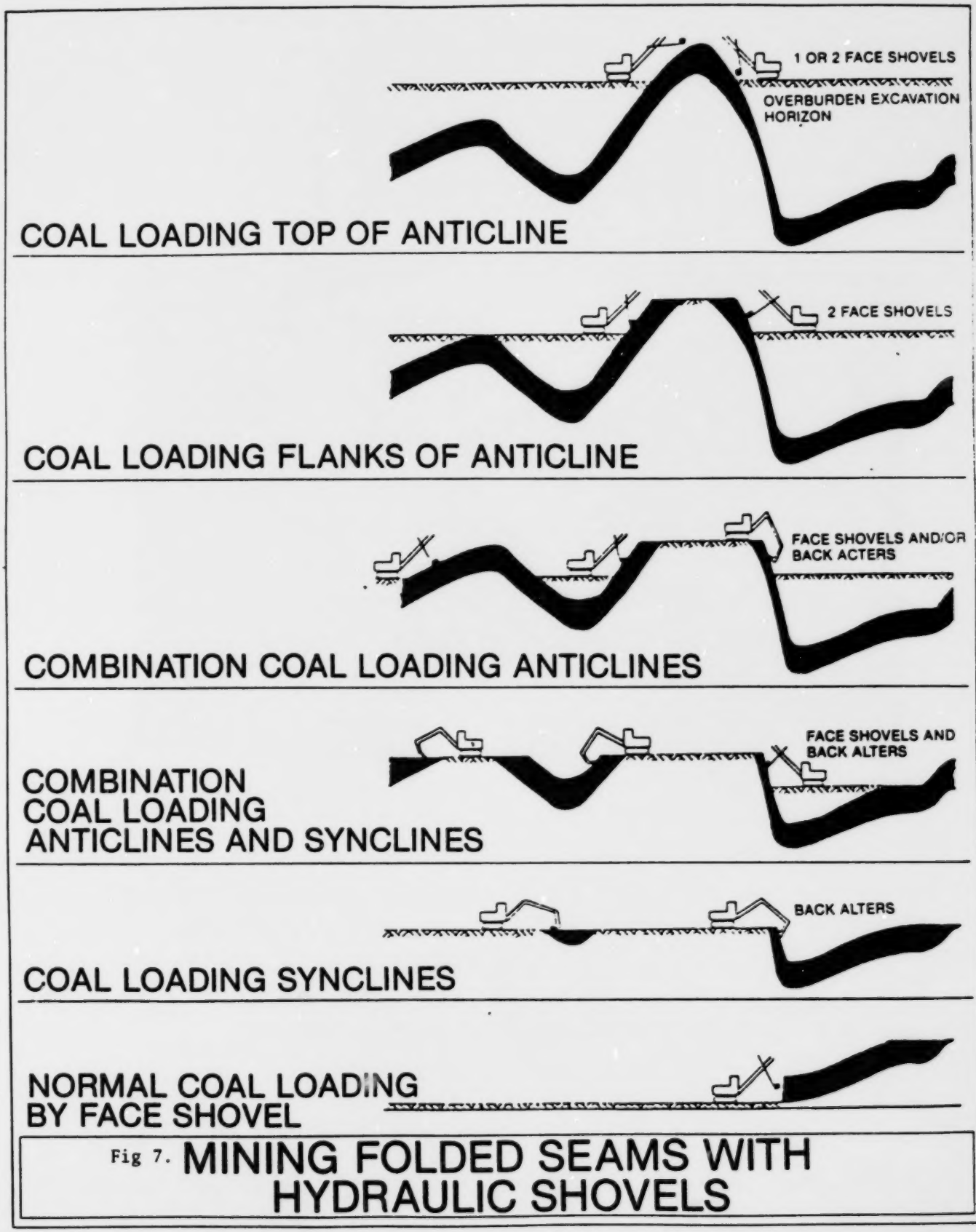

1 OR 2 FACE SHOVELS
OVERBURDEN EXCAVATION HORIZON
COAL LOADING TOP OF ANTICLINE
2 FACE SHOVELS
COAL LOADING FLANKS OF ANTICLINE
FACE SHOVELS AND/OR BACK ACTERS
COMBINATION COAL LOADING ANTICLINES
FACE SHOVELS AND BACK ALTERS
COMBINATION COAL LOADING ANTICLINES AND SYNCLINES
BACK ALTERS
COAL LOADING SYNCLINES
NORMAL COAL LOADING BY FACE SHOVEL

Fig 7. MINING FOLDED SEAMS WITH HYDRAULIC SHOVELS

Fig 8. Selective mining with a hydraulic shovel

mining. Due to shorter angle of swing, the cycle time for a given duty is lower and the productivity correspondingly higher.

All classes of loading equipment have undergone design changes, including the incorporation of health monitoring systems resulting in increased reliability and improved performance. In turn, this has resulted in lower unit cost of production. Equipment size mix has also changed to make loading equipment more compatible with hauling equipment.

In the case of cable shovels particular mention must be made of the Acutrol system incorporated in Bucyrus-Erie's cable shovels. The Acutrol is a static AC control and drive system offered by Bucyrus-Erie Company and manufactured by either General Electric or Siemens. The AC system offers numerous advantages over more conventional static DC drives. It provides an excellent average power factor; tolerance of momentary voltage fluctuations of 10 to 30% without shutdown or component failure; full electrical braking during loss of incoming power and lower harmonics of any static excavator drive. In terms of shovel performance it provides high digging speeds; faster handle retracting, reduced swing cycle time, improved hoist acceleration and high continuous propel gradeability. Because AC motors have better thermal (overload) protection than DC motors and can operate near stall conditions for an extended period of time, the Acutrol power system also provides better digging capability in hard materials without motor damage.

Hydraulic shovels are produced by several manufacturers in various sizes. The main components of a hydraulic shovel are undercarriage, upper structure, digging attachment, prime movers either diesel engines or electric motors, hydraulic pumps etc. The hydraulic cylinders used for boom maneuver generate enormous forces to be taken by the structural steel work. Machines designated for use in sub-zero climate must have load bearing components made from cold - weather steel. Hydraulic shovels operating in northern Canada where temperatures dip to -45° C or lower embody special features viz

- load bearing components as well as bolts subject to high stresses must be made from cold weather steel
- heating of engine cooling water is provided when the machine is idling
- heating elements for warming the hydraulic oil
- pre-heating of batteries by means of hot plates

Hydraulic shovels with dual type of prime movers are available although this option increases the cost. A diesel engine operated shovel can be converted to an electric powered machine and vice versa.

Another development which is being increasingly applied to surface mining loading equipment and is available as an option is the health and performance monitoring technology. This is achieved by using an on board

SHIFT TIMES: 5:00 to 17:00 DATE SHIFT BEGAN 23/FEB/86

1. PRODUCTION SUMMARY: (DENSITY = 1.50 T/CM, BUCKET WT = 37.T)

A. PRODUCTIVE DIGGING

	TIME ANALYSIS		RETURN MAT.		DIGGING ANALYSIS		
CODE DESCRIPTION	HOURS	%T	TONNES	CM	TONNES	CM	CM/HR
00 STRIPPING	6.64	55.33	46.	30.	24789.	16533.	2490.
02 KEY CUT	1.04	8.66	0.	0.	3315.	2210.	2125.
08 TRAINING	0.75	6.25	0.	0.	2041.	1361	1815.
14 OTHER DIGGING	0.14	1.16	0.	0.	486.	324.	23.
SUB TOTAL	8.57	71.42	46.	30.	30631.	20368.	2377.
B. NON-PRODUCTIVE DIGGING							
15 REHANDLE	0.66	5.50	0.	0.	2460.	1636.	2478.
16 ROADS	0.33	2.75	0.	0.	1230.	818.	2479.
SUB TOTAL	0.99	8.25	0.	0.	3690.	2454.	2479
TOTAL	9.58	79.82	46.	30.	34322.	22822.	2382.

2. WALKING SUMMARY:

	HOURS	%T	NUMBER OF STEPS
18 NORMAL WALK	0.17	1.42	12
19 OTHER WALK	0.03	0.25	2
TOTAL	0.02	1.67	14

3. OPERATOR DELAY:

	HOURS	%T
22 SHIFT CHANGE	0.07	0.59
23 MEALS	0.52	4.34
26 BLASTING	0.20	1.66
TOTAL	0.79	6.59

4. OPERATING MAINT:

	HOURS	%T
40 DUMP RIGGING	0.15	1.25
42 TEETH	0.13	1.08
TOTAL	0.28	2.33

5. ELECTRICAL MAINT:

	HOURS	%T
55 HOIST GENERATOR	0.54	4.51
TOTAL	0.54	4.51

6. MECHANICAL MAINT:

	HOURS	%T
TOTAL	0.00	0.00

7. SYSTEM:

	HOURS	%T
100 UNIDENTIFIED	0.61	5.08
TOTAL	0.61	5.08

PRINTED 23 FEB/86 AT 17:25 TOTAL HOURS RECORDED THIS REPORT

Fig. (9) A typical report generated by computerized mine management system (Digmate System for Draglines - General Electric).

performance monitoring technology. This is achieved by using an on board computer and a variety of sensors. Such systems available from the shelf are now in use on shovels, front-end loaders, draglines, scrapers and dozers. They monitor engine, drive train, hydraulic and lubrication systems to provide immediate warnings of impending systems failures before they occur. Periodic system checks can also be made by the operator to alert him to potentially hazardous conditions. Performance data, operating time and machine utilization, which has been recorded during regular work hours is contained in tabular form and on histograms for maintenance and operating management (Fig 9).

DRAGLINES

Draglines, when correctly applied, give the lowest unit cost of overburden removal compared with all other equipment except a bucketwheel excavator. Draglines can handle coarse material, can dig above and below grade and are capable of selective mining. The major disadvantages of a dragline is its lower breakout force compared with shovels, small transport distance requiring rehandling of materials and high initial capital cost.

In the majority of the surface mine operations the removal of overburden represents a significant portion of the overall cost. As the overburden cover lying over a coal seam increases so does the cost of its removal. In such situations draglines have longer cycle times because of chop down for bench formation and because of deeper digging. Methods have been proposed and applied to remove some part of the upper overburden by a supplemental mining system, so that the dragline continues to dig at its peak rate without a need to rehandle material. The methods to remove the upper overburden include scrapers, shovel/trucks, a long boom dragline and bucketwheel/conveyors, Fig (10).

There is hovever general agreement that for overburden depth of upto 30m and providing the geometry of the deposit and other mine planning issues permit a dragline is the most economical machine. For overburden depths of between 30 to 45m either a dragline with a long boom or a tandem dragline should be considered. At depths of 45 to 60 m a single dragline is not competitive and a pre-stripping system should be considered to support it.

CONTINUOUS MINING SYSTEM: BUCKETWHEEL EXCAVATORS - CONVEYORS

The main components of a continuous mining system are shown in Fig (11). The system comprises the bucketwheel excavator to continuously dig the material; conveyors to transport the material; trippers to transport the material from the conveyor to the spreader and spreaders to dump and spread the overburden by low or high dumping. However, the life line of a continuous surface mining system is a bucketwheel - conveyor combination. Conventional bucketwheel excavators have been used in Europe for decades in high volume surface mining operations and are finding increasing acceptance in many other parts of the world.

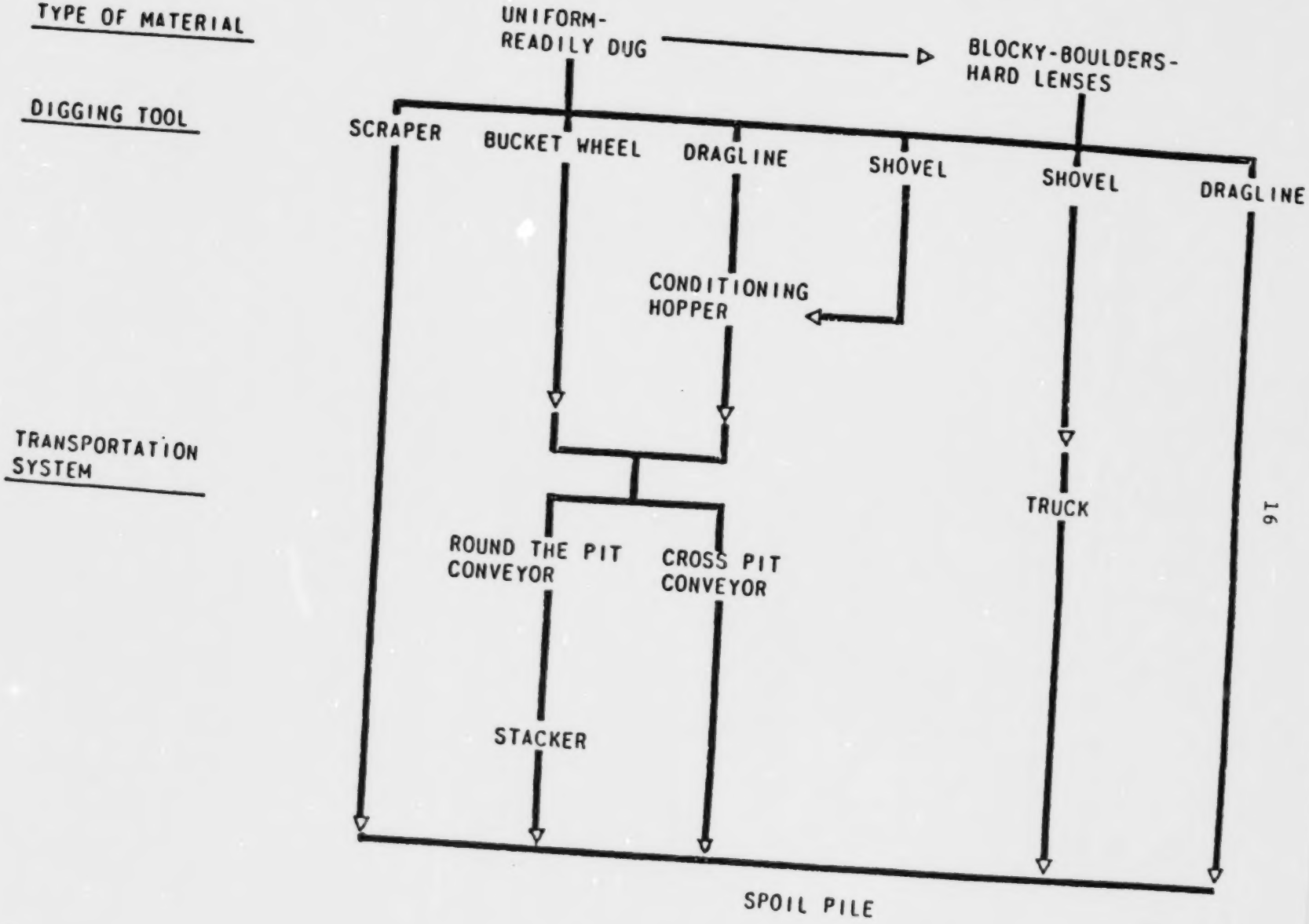
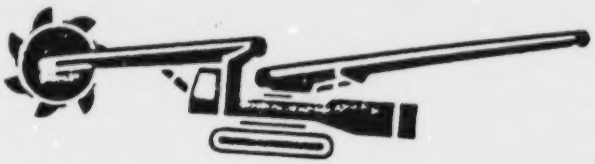
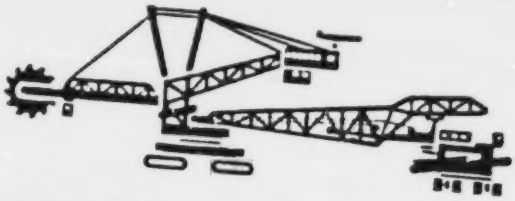


Fig 10. UPPER OVERBURDEN REMOVAL METHODS
USED IN CONJUNCTION WITH A DRAGLINE

COMPACT BUCKET WHEEL EXCAVATORS



LARGE-SCALE EXCAVATORS

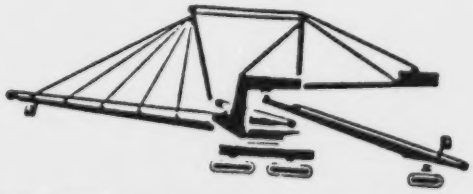


CONVEYOR BRIDGES AND BELT WAGONS

BELT CONVEYOR SYSTEMS

TRIPPER CARS

SPREADERS



MAIN COMPONENTS OF A HIGH-VOLUME CONTINUOUS SURFACE MINING SYSTEM

Fig 11.

A bucketwheel excavator, produces small sized material, can dig above and below grade onto a variety of haulage modes including trucks and belt conveyors and is capable of selective mining. Its main disadvantage is its lack of mobility and its unsuitability in digging consolidated materials. In some instances material to be handled by bucketwheels is blasted to facilitate digging.

The production rate of a bucketwheel excavator depends on many parameters of bucketwheel design, the nature of the materials to be excavated and the method of working a face. The number, shape and size of buckets, design of digging wheel and its diameter, length of the load boom, wheel rpm, slew and lifting speeds, and travel speed are some parameters associated with equipment design. The cuttability, plasticity, stickiness and moisture content influence the properties of the material to be excavated whereas design of cuts, geometry of the mining face in particular its height, width and slope angles relate to the method of excavation.

Conventional bucketwheel excavators are available in various sizes. The largest is capable of handling 240,000bm^3/day. For small to medium size operations a series of all hydraulic compact bucketwheel excavators and belt wagons are available. The output range of these machines is between 300 and 2000 bm^3/hr. (Fig 12).

These machines can be equipped with either electric or diesel power drives. The bucket wheel drive, boom lifting, slewing and traversing are all accomplished hydraulically. They have high mobility and are better able to cope with peak digging forces and changing excavating conditions. Delivery time of these excavators is short and the price relatively low.

TRANSPORTATION BY CONVEYORS

Belt conveyors provide an economical method of transporting large volumes of materials in surface mines. They are an integral part of the continuous mining systems. Although their initial cost is high operating costs are much lower. They are reliable and can achieve 90 - 95% availability.

There are many types of conveyors - shiftable conveyors, curved conveyors and mobile conveyors which are either on tracks or tires and which are moved about frequently. There are telescopic headstations and walking headstations which increase the scope of conveyor utilization and make conveyor moves easier and less time consuming. The intent of all these developments in conveyor technology is to transport material at the lowest unit cost.

High speed belt conveyors with the present technology can achieve speeds of up to 7.5m/sec; depending on its length and the material transported such a conveyor can be powered with upto 6 x 2000 kW units. For most long haul high lift applications steel cable belts are used. A 3.m wide belt is not

Fig 12. Demag compact all-hydraulic bucketwheel excavator-HD710

uncommon on high volume operations handling 30-40000 tonnes/hr. of materials.

A new competitor to long belt conveyor systems is the cable belt conveyor. The system is by no means new in origin but like other equipment described here it has undergone substantial design changes and consequent improvement in performance, reliability and operating cost.

A special feature of the cable belt system is the separation of the driving medium from the material carrying medium. In conventional systems the belt must be capable not only of carrying the material load but also transmit the driving tension. In the cable belt system the material is carried on a transversely stiffened but longitudinally flexible belt riding on two endless loops of cables that transmit the driving tension. (Fig. 13).

The drive cables with the belt sitting on them are supported on pulleys spaced at regular intervals along the conveyor. The belt is positively located on drive cables by the "V" shoe forms. Drive cables are located in grooves onthe supporting pulleys, range indiameter from 32mm (1 1/4") to 64mm (2 1/2") and can be sheathed in synthetic rubber.

Many of the economies in using cable belt conveyor systems emanate from the line equipment. Less line equipment and less moving parts are required to support the cables and belting. This results in reduced foundation and installation work compared to conventional type systems.

HIGH ANGLE AND CROSS PIT CONVEYORS

During the last five years, considerable research and development effort has been directed towards developing high angle, elevating and cross pit conveyors.(Fig. 14) Such conveyors where applicable can result in substantial reduction in transportation costs per unit of material handled. Even greater economy can be realised by changes to mine plans possible with such equipment. Elimination and re-positioning of some haul roads in a deep pit can reduce waste to be handled by millions of cubic metres.

The first prototype high angle conveyor (HAC) was developed by Continental Conveyor and Equipment Co. Inc. Alabama, U.S.A. This system uses a mechanically pressed "sandwich" belt. The 30.5 m long prototype unit had a 1.52 m wide belt and could be elevated up to 60°. Many types of materials including coal and lignite under wet and dry conditions were tested with throughputs of up to 2700 tonnes/hr. In 1984 one such conveyor was installed by Continental at Triton Coal Co., Buckskin Mine, Wyoming, United States. This conveyor has 33 m of lift operates at a 60° incline and can handle coal at 2000 tonnes/hr. (Fig. 15)

A second HAC will soon be erected at the Majdanpek copper mine in Yugoslavia. This conveyor will be an integral part of an in-pit crushing and conveying system and will elevate the crushed ore from the pit onto an out-of-pit conveyor system which will convey the ore to a processing plant.

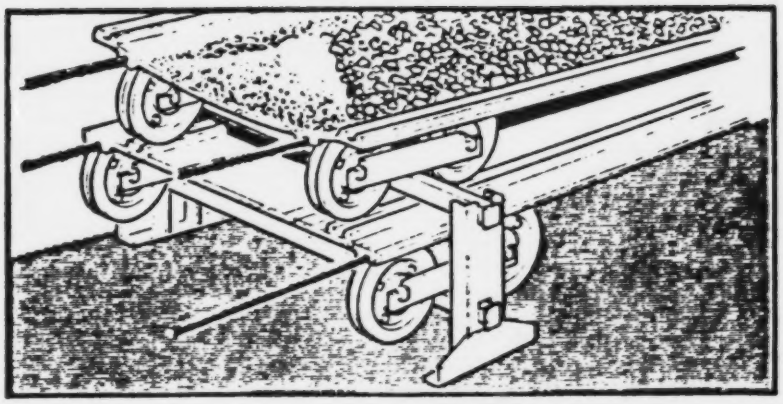


FIG. 13. SECTION OF CABLE BELT CONVEYOR

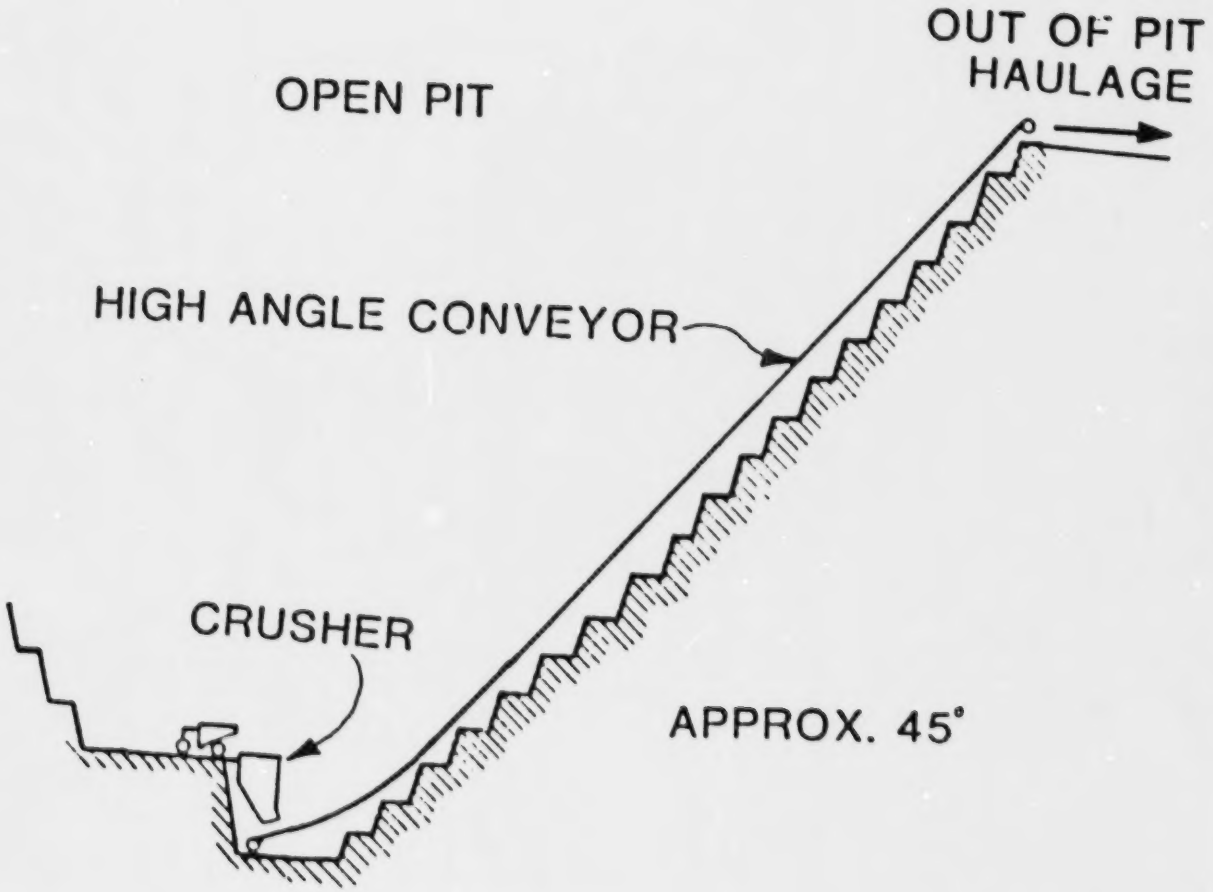


Fig 14 - high angle conveying system

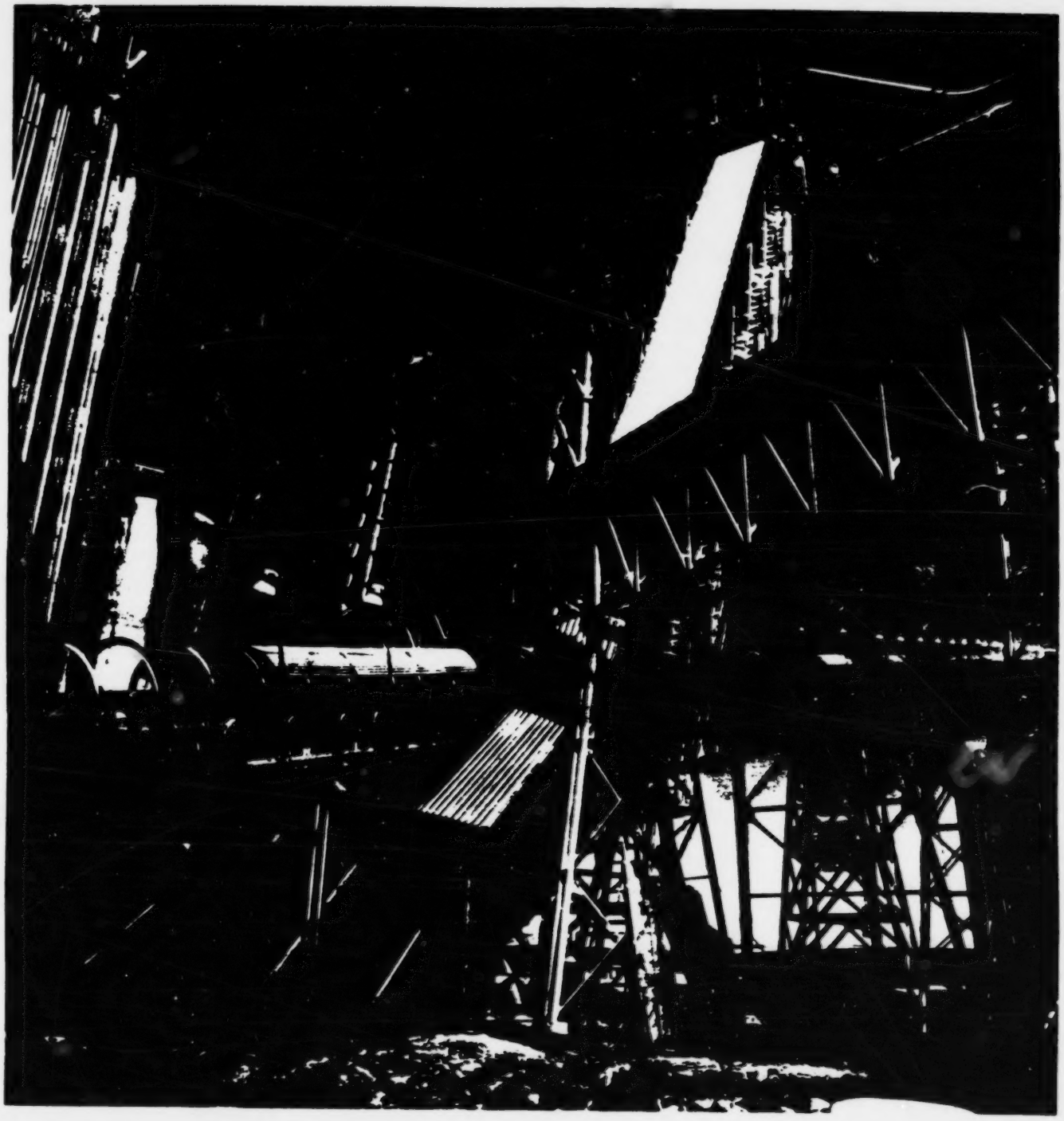


Fig 15. Continental high angle conveyor at Triton Coal Mine

This HAC will be 2m wide, have lift of 93.5 meters and is designed to convey minus 250mm copper ore at a rate of 4000 tonnes/hour up a 35.5 degree incline.

Table (4) gives the salient statistics on the three HAC designed and manufactured todate.

Although only limited field experience is available with HAC it is visualised that such conveying systems can offer numerous advantages over other modes of diesel consuming haulage systems particularly trucks. The HAC are:

a) More efficient energy users - trucks deliver their payload plus their own dead weight which can range up to 45% of total gross hauled weight. In a HAC much of the energy goes towards elevating the material.

b) More efficient for elevating materials to great heights - trucks costs increase exponentially with increase in lift height. HAC are less labour intensive.

c) More mobile - a HAC has the capability of being moved to different sections of the mine for more efficient use of the system. With conveying angles of up to 60^{0} the amount of additional excavation required to install a high angle conveying unit in minimal.

Additionally, HAC can be supported along any stable slope. Excavation required to install the conveyor is determined by geotechnical stability and not by 8 to 10% maximum slope required for truck haulage ramps. Some ramps can be eliminated entirely during the mine planning phase. In any event expense involved in maintaining the ramps in reduced.

High angle conveyors can be built with belt widths of up to 3m to carry up to 9000 tonnes/hr, provide a lift of over 300 m with steel cord belt and angles of slope up to 60^{0}. The conveyor can be mounted on rails, rubber tires, crawler type transporters and can even be fitted with walking mechanisim for optimum mobility. (Fig 16,17).

Variations in HAC designs are also available. For example, more recently Marion designed HAC for single lift and multiple lift pit operations. In this design a Flexowall pocket type belt is used instead of a mechanical sandwich belt. The conveyor can be equipped with either a fixed discharge for side-by-side loading of trucks, a hopper or a second highwall conveyor (Fig18).

A cross pit conveyor, as the name suggested is a conveyor transporting material across the pit. Combination of various conveyor schemes and configurations have resulted in around the pit conveyor etc. (Fig 19)

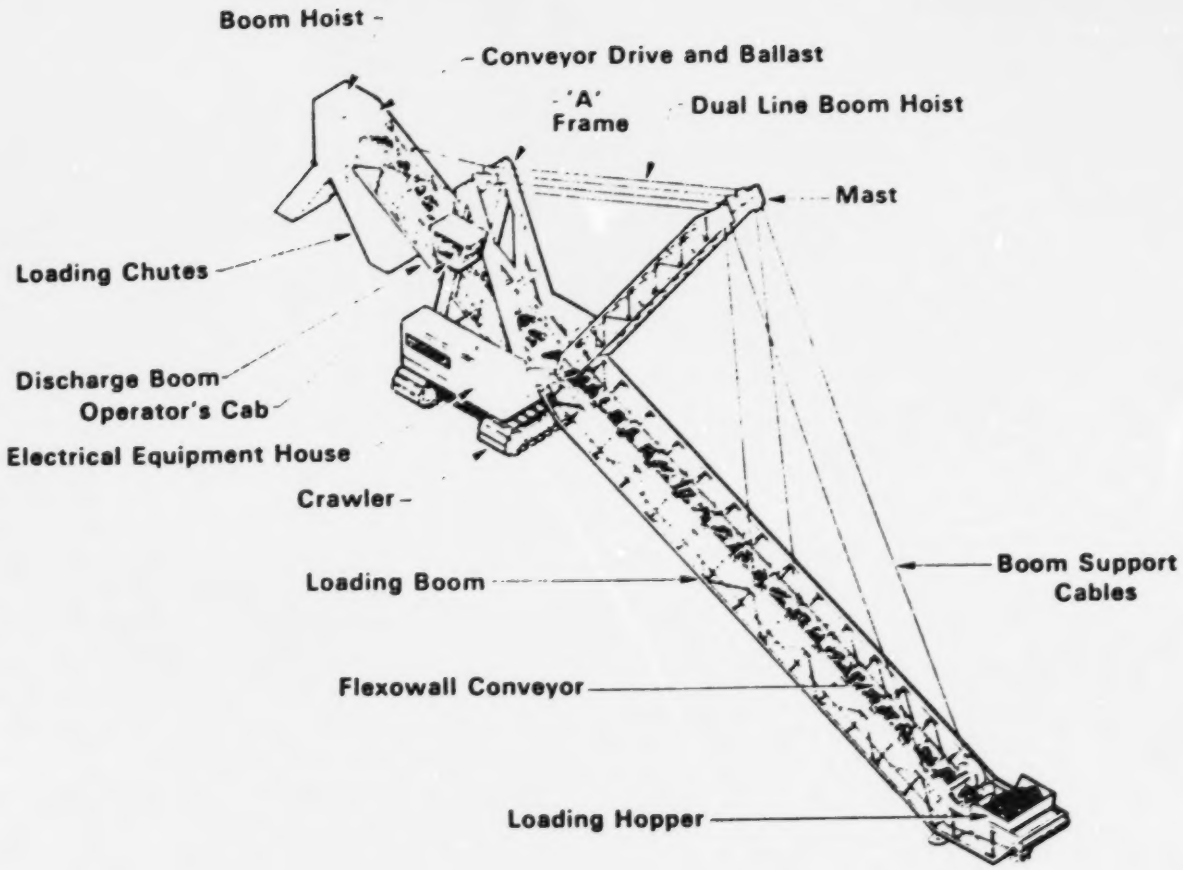


Fig. 16 - Marion-independently propelled crawler-mounted high angle conveyor

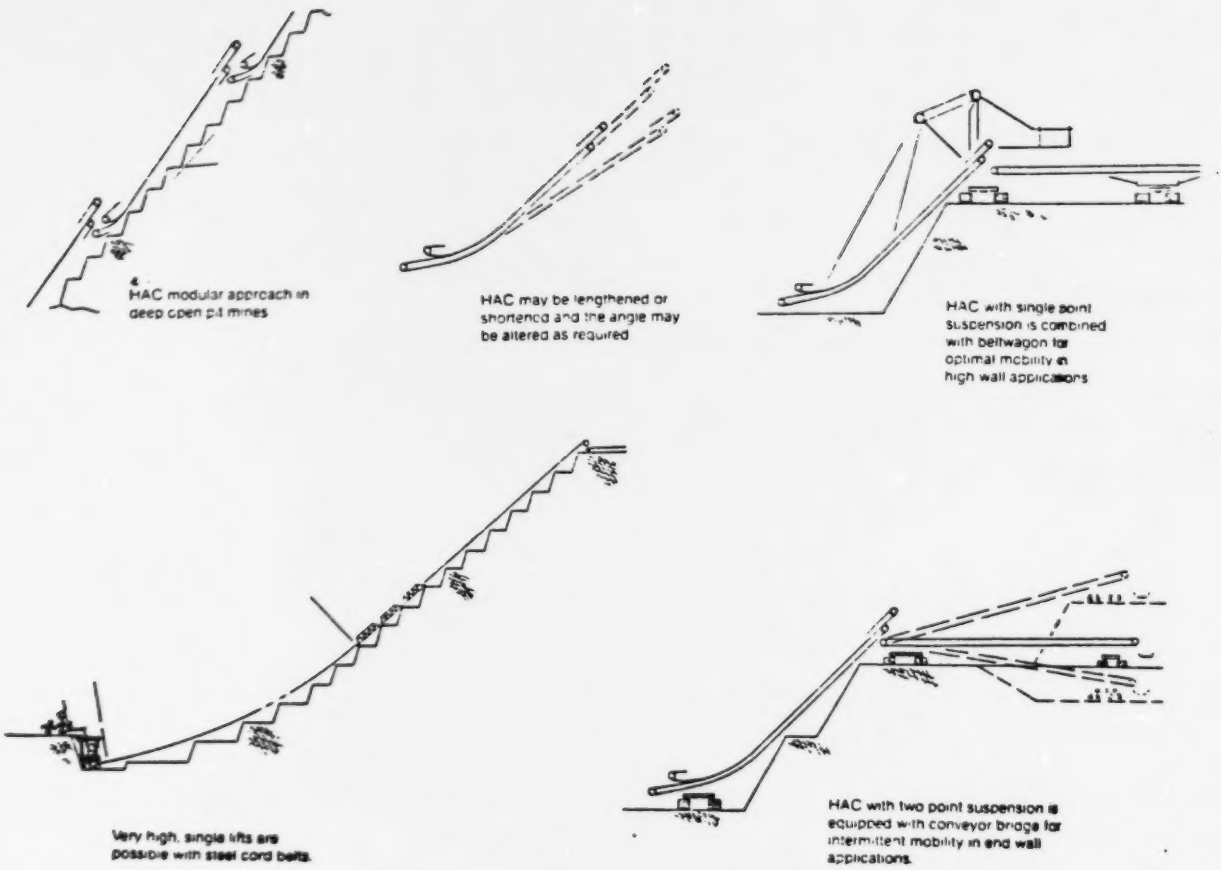

HAC modular approach in deep open pit mines
HAC may be lengthened or shortened and the angle may be altered as required
HAC with single point suspension is combined with beltwagon for optimal mobility in high wall applications
Very high, single lifts are possible with steel cord belts.
HAC with two point suspension is equipped with conveyor bridge for intermittent mobility in end wall applications.

Fig. 17 - Possible variations in high angle conveyor design and application (Continental Conveyor Company)

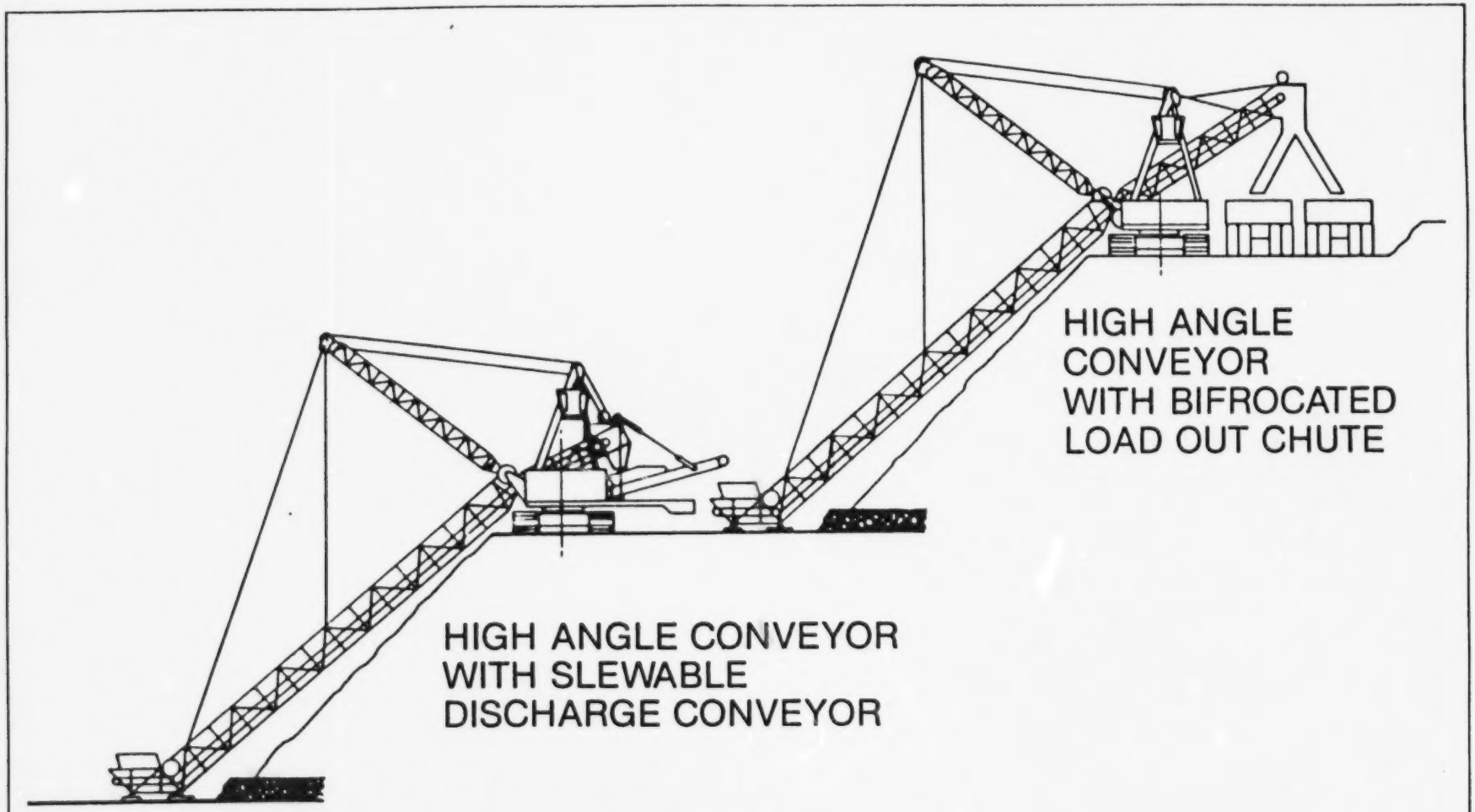


Fig 18.

TWO BENCH OPERATION OF HIGH ANGLE CONVEYOR

Table 4

HIGH ANGLE CONVEYOR - HAC® TEST AND DEMONSTRATION UNIT DATA

MATERIALS CONVEYED:	LIGNITE, COAL, COPPER ORE AND WASTE ROCK, IRON ORE PELLETS, SAND, GRAVEL, GRAIN
CONVEYING ANGLE:	VARIABLE FROM 30° TO 60°
DESIGN CONVEYING RATE AT 60° ANGLE:	1955, 2468, 2684 MTPH (2155, 2721, 2959 STPH) RESPECTIVELY FOR MATERIALS OF DENSITY .8, 1.6, 2.4 MT/CUM (50, 100, 150 PCF)
BELT WIDTH:	1524 MM (60 IN.)
BELT SPEED:	INFINITELY VARIABLE FROM 0 TO 6.1 M/S (0 TO 1200 FPM)
ELEVATING HEIGHT:	VARIABLE 7.9 TO 19.5 M (26 TO 64 FT.)
OVERALL CONVEYOR LENGTH:	35 M (115 FT.)
HAC CONVEYOR DRIVES:	
TOP BELT:	74.6 KW (100 HP)
BOTTOM BELT:	111.8 KW (150 HP)

TRITON COAL COMPANY HIGH ANGLE CONVEYOR - HAC® DATA

MATERIAL CONVEYED:	COAL
CONVEYING ANGLE:	60°
CONVEYING RATE:	
DESIGN:	1814 MTPH (2000 STPH)
SURGE:	1996 MTPH (2200 STPH)
BELT WIDTH:	1524 MM (60 IN.)
BELT SPEED:	4.65 M/S (915 FPM)
ELEVATING HEIGHT, LOADING POINT TO DISCHARGE:	32.9 M (108 FT.)
HORIZONTAL PROJECTION:	
LOADING POINT TO SANDWICH ENTRANCE AT 0° CONVEYING ANGLE:	11.0 M (36 FT.)
SANDWICH ENTRANCE TO DISCHARGE:	25.6 M (84 FT.)
OVERALL CONVEYOR LENGTH:	56.7 M (186 FT.)
HAC CONVEYOR DRIVES:	
TOP BELT:	112 KW (150 HP)
BOTTOM BELT:	149 KW (200 HP)

HIGH ANGLE CONVEYOR - HAC® FOR MAJDANPEK COPPER MINE IN YUGOSLAVIA

MATERIAL CONVEYED:	COPPER ORE
DENSITY:	2.08 MT/M^3 (130PCF)
LUMP SIZE:	250 MM (10 IN.) MAX
CONVEYING ANGLE:	35.5°
CONVEYING RATE:	4000 MTPH (4409 STPH)
BELT WIDTH:	2000 MM (78.7 IN.)
BELT SPEED:	2.67 M/SEC (525 FPM)
ELEVATING HEIGHT:	93.5 M (307 FT.)
HAC CONVEYOR DRIVES:	
TOP BELT:	450 KW (600 HP)
BOTTOM BELT:	2x450=900 KW (1200 HP)

CONCLUDING REMARKS

One of the most important developments in loading equipment for the surface mining industry in recent years has been the hydraulic shovel. Its use is expected to expand providing stiff competition to cable shovels and front-end loaders. Hydraulic shovels have been incorporated in some novel material handling concepts such as hydraulic-hopper-spreader combination (Fig 20).

The most visible change in the industry is the greater application of conveyor transportation technology. A high angle conveyor is a very promising development and should contribute significantly to surface mine economics. The application of HAC technology and further developments in this area will be carefully monitored.

Development and acceptance of compact bucketwheel excavators and mobile conveyors have provided an opportunity to introduce continuous mining to low volume operations.

Micro-processor based production information gathering and equipment health monitoring systems have been introduced and are finding greater acceptance within the surface mining industry. Their increased use is on the horizon.

ACKNOWLEDGEMENT

In preparing this review paper the author has drawn from numerous published and unpublished sources. The co-operation of equipment manufacturers, their field repressentatives and the staff of various research agencies particularly the U.S Bureau of Mines and National Coal Board U.K. is gratefully acknowledged.

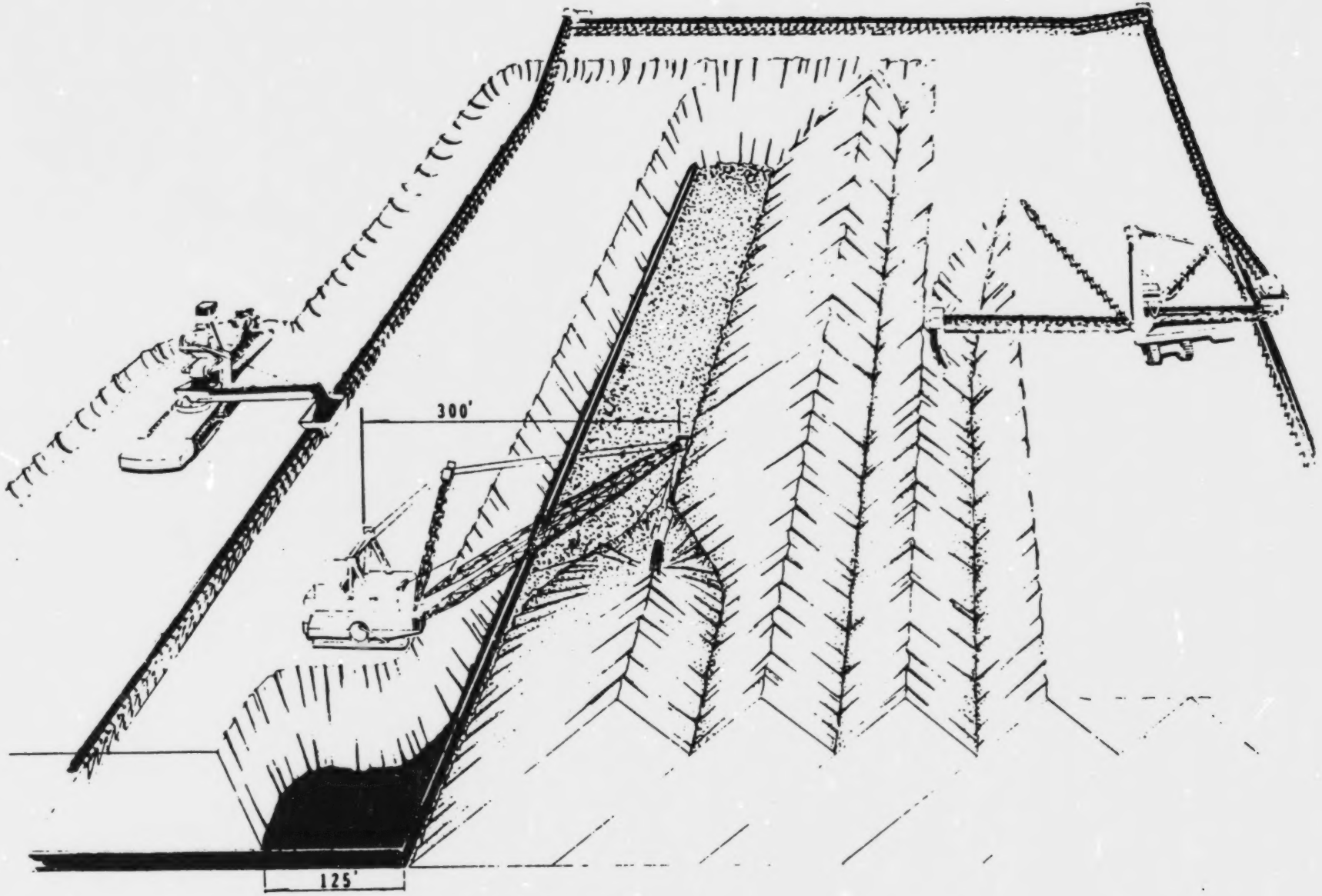
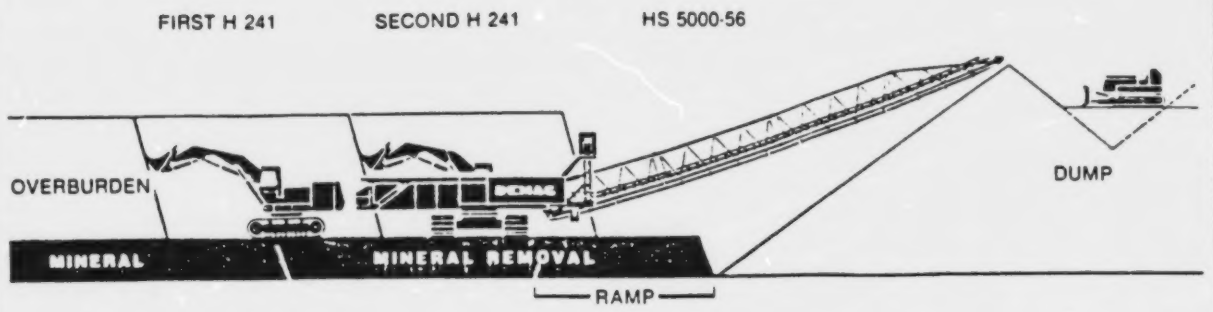


Fig 19. 2570-W 110 CUB. YD. BUCKET 300' REACH
ROUND THE PIT CONVEYOR BUCKET WHEEL LOADING WITH STACKER



HYDRAULIC SHOVEL EXCAVATES THE OVERBURDEN WHICH IS DUMPED INTO MINED OUT AREAS BY A HOPPER SPREADER

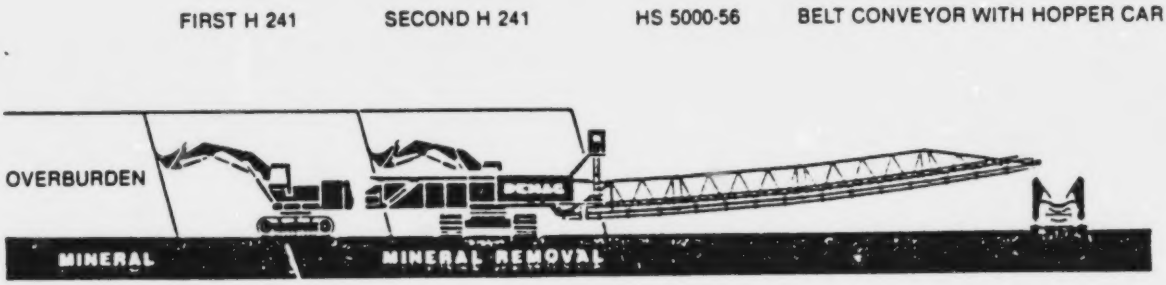


Fig 20.

HYDRAULIC SHOVEL LOADS THE BELT CONVEYOR VIA A HOPPER SPREADER

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STEEP SEAM COAL MINING IN WESTERN CANADA BY OPEN PIT MINING

Raj K. Singhal and Dave G. Osborne

January 1984

For presentation at the 113 Annual Meeting in Los Angeles, California, February 26 - March 1, 1984.

ENERGY RESEARCH PROGRAM
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Abstract. Canada produces close to 42 million tonnes of coal per annum of which some 38 million tonnes is produced by surface mining methods. The two Western Canadian provinces, Alberta and British Columbia, produce 31 million tonnes of coal by surface mining. These two provinces provide the bulk of the metallurgical coal for export.

The geological conditions in the Western provinces particularly in the mountain region are complex. The coals are friable and the seams are steeply inclined, sheared, intensely folded and faulted. There may be as many as 15 to 20 coal seams present with true thickness ranging from 2.5 m to over 6 m.

This paper reviews the surface mining methods used to extract such seams. The difficulties associated with steep seam and multiple seam mining of friable coal resulting in lower coal recovery, high dilution and the problem of cleaning fine coal in the wash plant have been highlighted.

Geological Structure

Figure (1) shows the distribution of Canadian Coalfields whereas Figure (2) shows the coal deposits of Alberta and British Columbia. Several Canadian provinces have coal resources but Alberta is estimated to have the largest reserves of bituminous and sub-bituminous coal.

The province of Alberta is divided into three regions each containing deposits of similar age and characteristics. These are the Mountain, Foothills and Plains regions.

The Mountain Region extends along the eastern flank of the Rocky Mountains; it contains mostly medium and low volatile bituminous coal deposits mainly of Upper Jurassic and Lower Cretaceous age. The coals are commonly friable. The coal bearing strata are highly folded and faulted which has cuased considerable tectonic thickening and thinning of coal seams in certain locations.

The Foothills Region adjoins the eastern edge of the Mountain Region and contains mainly highly volatile bituminous coals of Upper Cretaceous and Lower Tertiary ages. Like their counterparts in the Mountain Region these coalfields have been sheared, faulted and folded, and in certain locations show considerable thickening and thinning of coal seams.

The Plains Region coal is mostly sub-bituminous in rank mainly of Upper Cretaceous and Lower Tertiary age. Most of the seams of this region are flat-lying except those close to the surface that have been glacially disturbed.

As can be seen in Figure (2) coal deposits of the province of British Columbia are widely scattered.

The coal deposits of southeastern British Columbia (Crowsnest Coalfield) are Upper Jurassic in age and are part of the southern end of the Mountain Region as described for Alberta, with the notable difference that they contain considerably more seams that are of greater thickness than in adjoining areas of Alberta. The coal deposits of northeastern British Columbia are however Cretaceous in age and are the northern extension of the coals that occur in the Mountain Region of Alberta. Several small basins of Tertiary coal occur in the south-central part of the province including Tulameen Princeton, Merritt and Hat Creek. Most of these basins contain coal seams which are intensely folded, faulted, and irregular in thickness.

The Energy, Mines and Resources Canada Report ER-79-9 by BIELENSTEIN et al. provides further details on the geological environment of Canadian coal deposits.

Coal Reserves, Recovery and Mining Losses

The estimation of mineable coal reserves, mining recoveries and dilution is a fairly complex process particularly where there are a number of seams separated by interburden of various thicknesses and lithologies. It is even more difficult for the steep dipping seams surrounded by distorted mountainous strata. The initial estimates of mineable reserves, recoveries and dilution are based on experience to be verified later by actual field experience and back analysis — but it is not an easy task. Even the estimation method varies from mine to mine depending on the complexities of the geological environment.

Some typical guidelines used for mineable coal reserve estimates, by way of example, are:

a) All seams greater than 1.5 m in thickness are mineable;

b) partings greater than 1.5 m in thickness can be selectively mined and rejected;

c) mining loss for each seam: 10 cm from the top of the seam and 10 cm from the bottom.

At another project in British Columbia where the coal bearing strata contained approximately 20 coal seams or split group with an aggregate coal thickness of about 90 m, the following criteria were applied in reserve estimation:

a. Coal Mining Member = one or more coal splits or seams of more than 60 cm true thickness each separated by one or more rock partings of less than 90 cm true thickness each
b. Coal in Place = the sum of all Coal Mining Members
c. Mining Loss = 30 cm of coal at the hanging wall of each Coal Mining Member
d. Raw Coal = Coal in Place minus Mining Loss (b-c)
e. Dilution = 15 cm of rock from the footwall

One of the most critical factors in steep seam mining in the mountains is the mining loss. Mining losses occur when top coal is removed with overburden or bottom coal left in place. Some factors which affect mining losses are the coal thickness, interburden, dip of the seams, mining of multiple seams, proximity of seams, spillage, size and type of mining equipment used and the geological complexities.

As a general rule 80 to 90 percent of coal is recovered from major seams dipping to up to 30° and not unduly disturbed by geology. From seams sandwiched between the distorted and broken strata, depending on the seam thickness, recoveries of 40 to 50 percent are obtained. In such cases dilution is very high. In case of thinner seams which are in close proximity to major seams, recoveries from the thin seams can be as low as 20 percent to nothing.

At places where structural deformation has resulted in thickening of coal seams (up to 15 to 20 m thick) improvement in coal recovery and coal reserve estimates are often noted.

Coal Quality

The formation process of Canadian coals under severe geological disturbance as described has resulted in a seam structure that is very different from coking coal deposits elsewhere. Much of the coal is severely sheared and the resultant coals are porous, prone to oxidation and massively fractured on a micro-scale. There is, therefore, a wide range of metallurgical coking coal in terms of individual properties comparable in some respects with the U.S. high and low volatile coals and Australian medium and low volatile coals. This range is of particular interest to coal purchasers seeking optimum blends for metallurgical coke manufacture. The structure of these coals greatly influences the physical, mechanical and chemical properties such as friability, moisture capacity, degree of oxidation and coking properties. All of these may in turn influence important product coal properties in subsequent mining, handling, beneficiation and processing.

The effects of handling and cleaning friable Rocky Mountain bituminous coals on size distribution can be seen in Table 1. The amount of fine coal resulting from mining and transporting raw coal to the coal preparation plant can be seen in Table 2.

In terms of coking properties, Rocky Mountain coals (being typical of non-marine coals) are characterized by total sulphur content of less than one percent and raw coal ash content of 10 to 30 percent by weight.

This mineral matter is composed primarily of kaolinite and quartz. The petrographic compositions of most of the coking coals show them to be rich in inertinite macerals, macrinite, fusinite and semifusinite, which are properties resulting in strong coke. When the mean maximum reflectance of vitrinite in oil Ro max is used as the coal rank parameter, this high inertinite content is further characterized by correspondingly low volatile matter contents, lower free swelling indices (F.S.I.), lower maximum dilatation and fluidities than other U.S. and Australian coal of the same rank. The Canadian coals are however richer in the reactive macerals, vitrinite, exinite and semifusinite. These combined properties of Rocky Mountain coking coals have been a major reason why such coals have been in demand by the Japanese steel industry as a major coke blend component.

Table 3 shows a classification of coking coal quality by group.

Mining Methods

In the provinces of British Columbia and Alberta most surface coal mines are open pit terrace operations. The operations use typical truck-shovel methods extracting multiple coal seams from several multi-bench work faces. Only one operation uses a dragline as the prime earth mover.

For the top soil removal scrapers are preferred.

In some areas where pioneering work such as clearing trees and brush is involved, front-end loaders, hydraulic shovels and dozers are used. Top soil is stockpiled for later use in reclamation. Unconsolidated overburden is removed by similar type of equipment.

Hard consolidated overburden is drilled and blasted. Blast holes are drilled with rotary crawler - mounted rigs using bits in the 22 cm to 31 cm diameter range. Typical hole depths are in the range of 12 to 18 m to accommodate the pit bench heights of 12 to 15 m. For a 12 m high bench a typical hole will be 14.6 m in depth including the subgrade drilling of 2.6 m. Typically, half of this hole will be powder column and half will be stemmed. For a 15.2 m bench a typical hole will be up to 18.3 m in depth including the subgrade drilling.

Typical drilling patterns are 9 m spacing and 9 m burden. Depending on local geological conditions and hole diameter selected drilling patterns of 8 m x 8 m, 8.5 m x 7.3 m and staggered patterns of 11 m x 5.5 m and 7.3 m x 3.7 m etc. are being used.

The primary explosive used for blasting is ANFO. In wet holes which can be dewatered the holes are lined with a plastic liner and then loaded with ANFO. Wet holes which cannot be dewatered are loaded with a water gel slurry. In harder rock, e.g. sandstone, aluminized ANFO (containing 3 to 7 percent of Al) or straight slurry is used. ANFO and slurry explosives are delivered in bulk loading trucks.

Typical powder factors (kilogram of explosive per BCM broken) are in the range of 0.36 kg/bm^3 to 0.70 kg/bm^3.

Overburden is excavated mostly by conventional shovels and front-end loaders; recently the hydraulic shovel has gained considerable acceptance. Electric cable shovels with 11, 19 and 23 m^3 rock dippers form the major excavation units. However on a dipping seam a wedge of waste is not accessible to a shovel. This wedge is dozed down and loaded into trucks by front-end loaders and hydraulic shovels.

Often more than one face is active on any one bench and sometimes work is in progress on several benches simultaneously using a combination of equipment described.

Overburden is hauled to waste disposal sites either in the pit or outside of it in rock-body trucks. The most popular size is 154 tonne but trucks of 90 tonne, 110 tonne, 180 tonne and in one case even 315 tonne are being used.

As has been noted Western Canadian coals are friable and do not require drilling and blasting. Coal is usually loaded by the front-end loaders and/or hydraulic shovels into coal body trucks. Front-end loaders and hydraulic shovels of up to 19 m^3 bucket capacity are being used.

An earlier practice of dozing coal down the footwall on moderately pitching seams (up to 30° inclination) is being gradually discarded. Travel of dozer on the coal bed results in excessive generation of fines causing severe problems in the coal wash plant. For this reason hydraulic shovel/backhoe is being used on an increasing scale for mining of moderately dipping coal seams.

In seams of varying quality where blending is necessary to meet the contract specifications, a dozer will normally push coal obliquely across

the seam to achieve blending of the footwall and hangingwall coal. The digging action of a hydraulic shovel provides the same end result.

In moderately dipping seams often footwall is followed. In steeper coal seams (30 to 90°) benching of the footwall is often necessary. Even in such situations a hydraulic shovel/backhoe is preferred. In multiple seam mining, particularly in tectonically disturbed strata, a hydraulic shovel permits greater degree of selective mining. In a couple of instances of steep seam coal mining smaller crawler draglines have been used to remove pit bottom coal.

Typically bench heights in Western Canadian pits are 12 to 15 m, overall pit slopes 45° to 50° with some localized steeper slopes. In seams dipping greater than 30° footwall is often benched to create safety berms. In some cases dewatering has been necessary to relieve artesian pressure and stabilize the pit walls; in others rock bolting of the footwall has been considered.

Haulage road widths determined by the size of the equipment in use are 25 - 30 m wide and grade between 6 to 10 percent. Because of the mountainous topography, switch back haulage roads are used in some pits. Safety ramps for stopping run-away trucks are provided.

Depending upon the topography at the mine site end tipping and area dumping (dumping in layers) of the overburden is carried out. In the mountainous region more often it is end tipping. End tipping normally does not permit compaction of the disposed material and this results in occasional dump failures. Waste dumps are usually terraced and settle to the angle of repose of the waste material between 35 to 37°.

Guidelines and government regulations exist relating to the reclamation of mined out pits, waste areas and other areas disturbed by the mining activity. Waste dumps are required to be sloped to an overall maximum of 27° for reclamation. Backfilling of the pit is usually carried out as soon as space is available. In almost all cases overburden is deposited externally to the pit for the first few years.

Coal Preparation and Handling

The first wave of large coal preparation plants in Western Canada were built in the early 1970s. Basically they used the standard British and U.S. technology.

It quickly became evident that these flow sheets were not suitable for the Western Canadian coals characterized by high fines content and inconsistent froth flotation properties. These factors combined with the severity of the Canadian winter caused many serious and costly problems.

Major design changes in the preparation plants and thermal dryers were made. The result has been the development of a flow sheet that has almost become a standard for treating these coals.

Using many of the lessons learned, the second generation plants of the early 1980s have been able to avoid many problems and pitfalls. A further change has been the need for some of them to prepare a thermal coal for export as well as the traditional coking (metallurgical) coal. The new plants are in the Crowsnest Pass area of British Columbia - Greenhills (Westar), Line Creek (Shell) and Byron Creek (Esso) and in the Peace River Area - Quintette (Denison) and Bullmoose (Teck).

The effects of multiseam mixing resulting in variable product coal yields and fluctuation in the amount of out-of-seam dilution are effectively overcome by some form of homogenization of the raw coal. The extent to which this is applied, being closely related to the variability of the raw coal, is usually greatly assisted by scheduling and handling of coal from the open pit to the plant site. No currently operational mine employs blending bed methods with complex stacker/reclaimer equipment largely because of the favorable washability characteristics of the coal. Each of the contributing coal seams, whether considered individually or mixed, create few cleaning problems and this obviates the need for a sophisticated blending approach. Accordingly, homogenization is largely accomplished by means of natural mixing created by a combination of raw coal handling and silo storage and reclamation.

In general the coals are readily cleaned without technical difficulty, providing that the individual raw coal feeds to each of the coal cleaning streams are adequately sized and/or classified prior to cleaning.

Table 4 shows the washability analysis for a 38 mm by 0.5 mm raw coal typical of Rocky Mountain coal, readily cleaned by dense medium cyclone.

Figure 11 shows a simplified flow sheet for one of the newly constructed plants which may be regarded as being typical of most plants producing metallurgical coking coal. Metallurgical coal product ash content is usually 7 to 9.5 percent.

The cleaning of thermal coal is carried out by a partial cleaning approach in the case of Line Creek and Byron Creek plants (coal plus 6 to 8 mm is washed; coal minus 6 to 8 mm is blended with wash coal without cleaning). At Quintette the thermal coal is cleaned in a Baum jig and at Greenhills a circuit similar to Figure 11 is used excluding the dense medium bath. Thermal coal product ash content is usually 12 to 16 percent.

Fine coal cleaning of metallurgical coal is carried out using one of two, more or less, standard circuits. For coals encountering little or no oxidation or weathering characteristics, the minus 0.5 mm coal passes from flotation with the concentrates being subsequently dewatered by either vacuum disc filters or screen bowl centrifuges. For coals with these problems, the fines are classified at 0.15 mm and the 0.5 mm by 0.15 mm fraction is cleaned by two-stage water-only cyclone while the minus 0.15 mm fraction is either cleaned by froth flotation or else discarded. The reason for this is that the coarse fraction has been shown to be poorly responsive to flotation and yet readily cleaned by cyclones. The converse is true for the 0.15 mm fraction. The two clean coal functions are then combined for filtration or centrifugal dewatering.

Conclusions

The major problems faced by the operators in

the Western Canadian coalfields are related to the recovery of in situ coal. Proper mining and quality control procedures are established in the pit to maximize coal recovery from the seam and minimize dilution. There is no one method of estimating mineable pit reserves, recoveries, mining losses and dilution. This is to be expected as geological conditions are very varied from one mine site to another. Even within the same pit a variety of seam(s) configurations can be seen.

The open pits of Western Canada are highly mechanized and use the most modern of mining equipment. Hydraulic shovels and belt conveyors for long distance transportation are two items which have gained remarkable acceptance within a very short time. High break-out force and capacity for selective mining has contributed largely to the success of the hydraulic shovel. There are some 20 such machines in operation in Western Canada.

Only one coal operator in the mountains uses a dragline. Draglines have not found that much of acceptance although several are being operated in the surface coal mines in the Plains Region.

The greatest constraint to overall mining in the provinces of British Columbia and Alberta is the topography. The rugged mountain terrain places numerous constraints on mine planning, materials handling and infrastructure development. The mines are located at elevations of up to 2400 m above the sea level. Temperatures during the winter dip as low as -45°C.

This type of climate requires that some special specific features be incorporated in the basic machines. For example, most load bearing components are made from cold weather steel. Provision is made for heating of the engine coolant when the machine is off-duty. Heating elements for heating the hydraulic oil after machine stoppages and pre-heating of batteries by means of hot plates are also required. The fuel oil warmer/water separators and air-system deicer systems are also essential for cold weather operation.

The Western Canadian mines have learnt to deal with the problem of friable coal. In pit mining techniques have been developed to minimize the production of fines. Trials with various sets of fine coal cleaning circuits have led to the adoption of froth flotation and water only cyclones.

The process plants incorporating the three cleaning circuits, e.g. dense medium, hydrocyclones and froth flotation tend to be relatively complex with a high capital cost but offer a great deal of flexibility in terms of feed variability and product quality.

On any coal mining project in the mountains the challenges facing the mine planners are enormous. The concurrent mining of several seams often provides a batch of raw coal of highly variable quality. The raw coal from these batches must be blended to provide a uniform feed for the coal processing plant with the aim of achieving a washed coal of a specific quality for the export market.

Several mining alternatives must be evaluated in order to find an optimal trade-off between production cost, selling price, resource conservation, product quality and environmental protection.

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Table 1. Size Distributions of Rocky Mountain Coking Coal

Size Fraction mm	Raw Coal As Mined Mass %	Raw Coal As Mined Ash Content %	Raw Coal Into Plant Mass %	Raw Coal Into Plant Ash Content %	Clean Coal After Drying Mass %
Plus 50	16.4	32.5	2.9	29.0	2.2
-50 +25	11.9	20.7	5.9	27.3	4.7
-25 +13	15.2	22.5	9.8	26.3	8.1
-13 + 6	15.9	26.4	13.6	28.2	9.5
- 6 + 3	9.9	27.0	11.1	28.3	18.3
- 3 + 0.5	19.0	22.2	29.9	22.2	21.7
- 0.5 + 0.15	10.4	16.6	14.0	16.4	20.5
Minus 0.15	1.3	17.3	12.8	11.8	15.0

(Reference 3. Butcher et al., 1979)

Table 2. Proportion of Fines in Rocky Mountain Coals

Mine	Hardgrove Grindability	Volatile Matter (dmmf)	Average Ash Content %	Fines Content % -28 Mesh
A (Semi-Anthracite)	79	13	9.5	31
B	89	25	10.5	24
C	96	22.5	12.5	30
D	89	32	12.0	28.5
E	82	30.5	9.0	23
F	91	19.5	8.0	40
G	105	25	9.5	35

(Reference 4. Mikhail and Patching, 1980)

Table 3. Coking Properties of Rocky Mountain Coals

Nippon Steel Grouping	Rank Ro max	Inert Content %	Maximum Dilatation %	Maximum Fluidity ddpm	FSI	Volatile Matter % (dmmf)
Kaystone	1.30	8 to 30	0 to 70	5-100	6-9	16-19
Pittston	1.0 - 1.4	8 to 30	80 to 260	1500-30000	7-9	22-34
Moura	0.9 - 1.2	25 to 45	-10 to -100	3-2500	5-8	25-32
Balmer *	1.2 - 1.5	25 to 45	-10 to +100	3-1500	5-8	19-26

* Predominantly Canadian Rocky Mountain Coals

(Reference 5. Pearson, 1980)

Table 4. Example: Washability of Rocky Mountain Coking Coal

Relative Density	Fractional % Yield	Fractional % Ash	Cumulative % Yield	Cumulative % Ash
Floats 1.30	36.14	2.28	36.14	2.28
-1.30 + 1.35	9.89	7.80	46.03	3.47
-1.35 + 1.40	9.03	11.34	55.06	4.76
-1.40 + 1.45	5.72	15.43	60.28	5.69
-1.45 + 1.50	3.20	19.66	63.48	6.39
-1.50 + 1.55	3.11	23.17	66.59	7.17
-1.55 + 1.60	2.05	27.75	68.64	7.79
-1.60 + 1.65	1.54	31.91	70.18	8.32
-1.65 + 1.70	1.50	35.80	71.68	8.89
-1.70 + 1.75	1.29	40.37	72.97	9.45
-1.75 + 1.80	1.24	44.24	74.21	10.03
-1.80 + 1.85	1.37	48.64	75.58	10.73
-1.85 + 1.90	1.33	52.27	76.91	11.45
Sinks 1.90	23.09	79.25	100.00	27.10

(Reference 10. Walters, 1983)

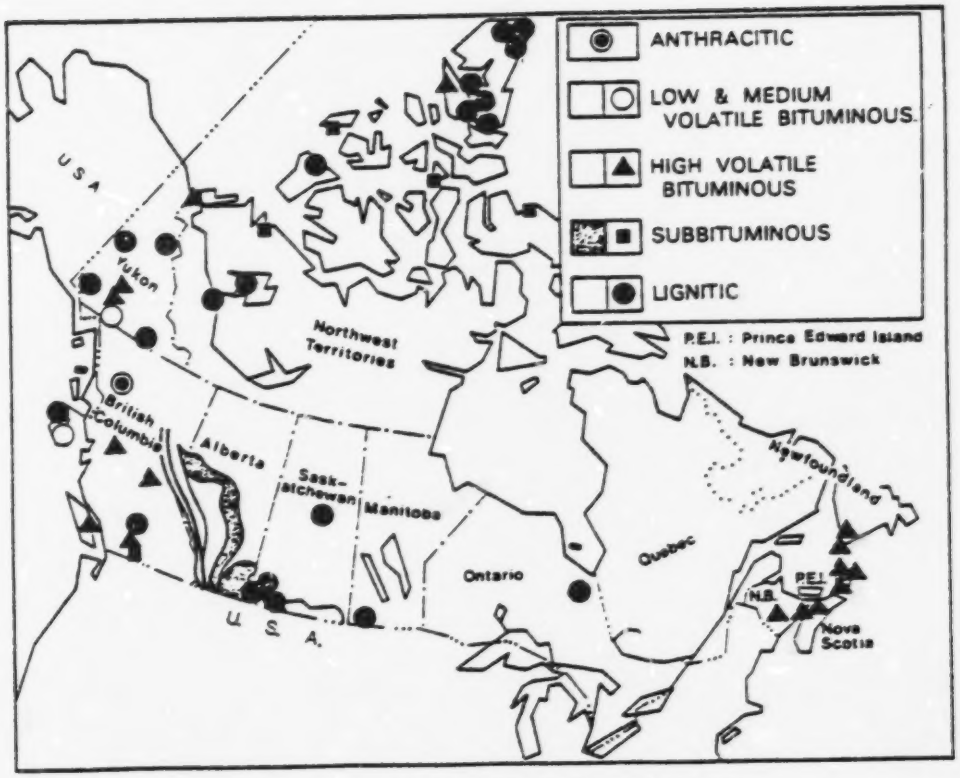


Figure 1. Coal in Canada (from Ref. 2).

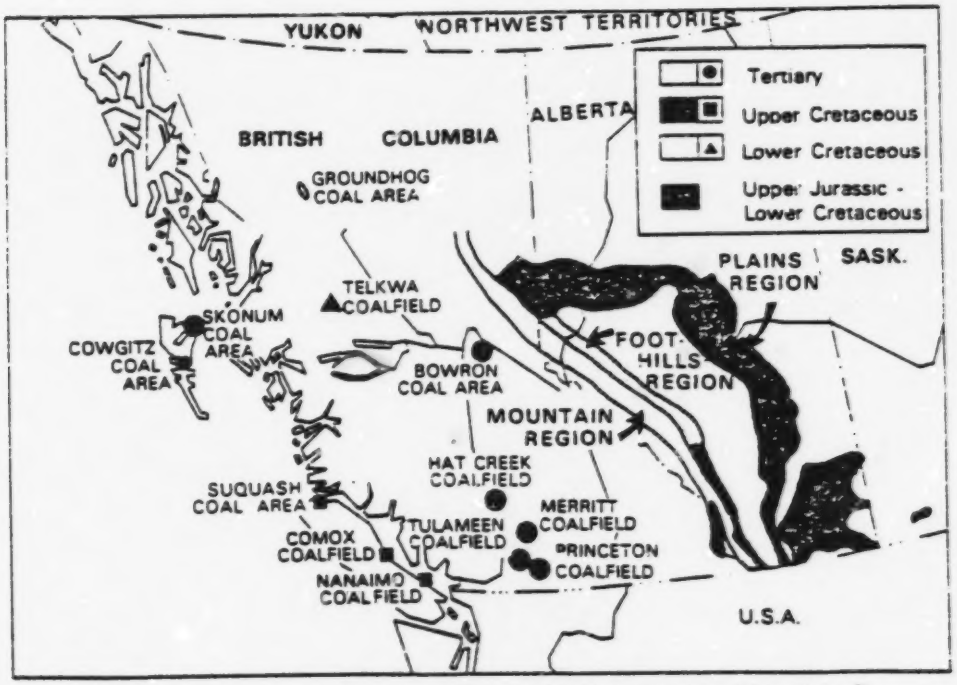
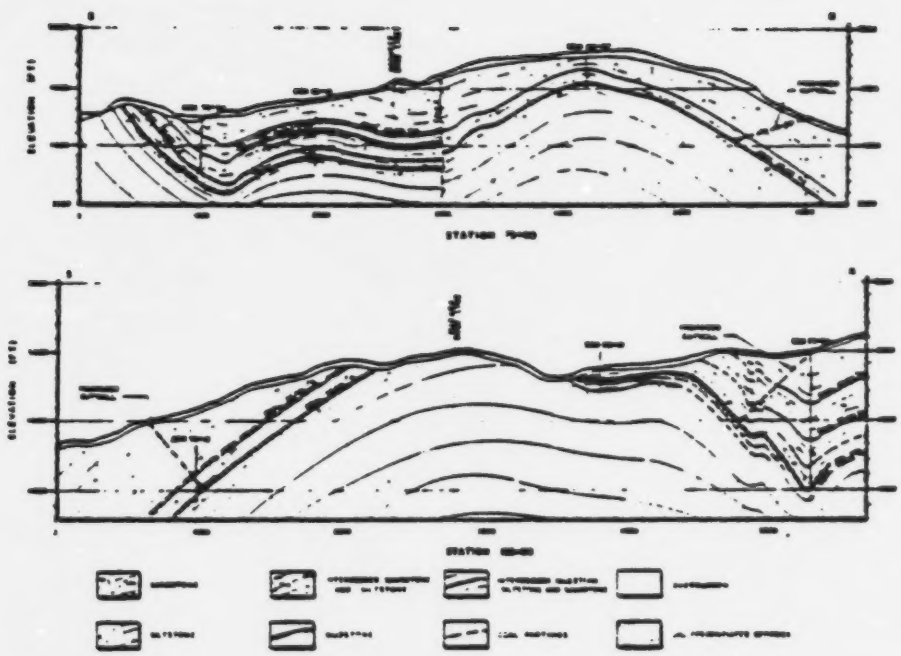


Figure 2. Coal Deposits of Alberta and British Columbia (from Ref. 2)



Figures 3 and 4. Typical geological sections showing coal seam structure in the Western Canadian Mountainous Region.

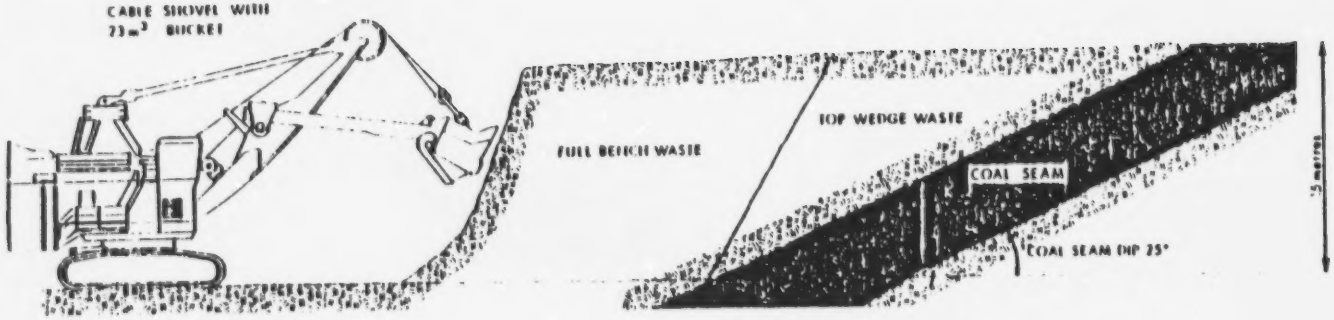


Figure 5. Range diagram of coal seam - digging by cable shovel (Ref. 6)

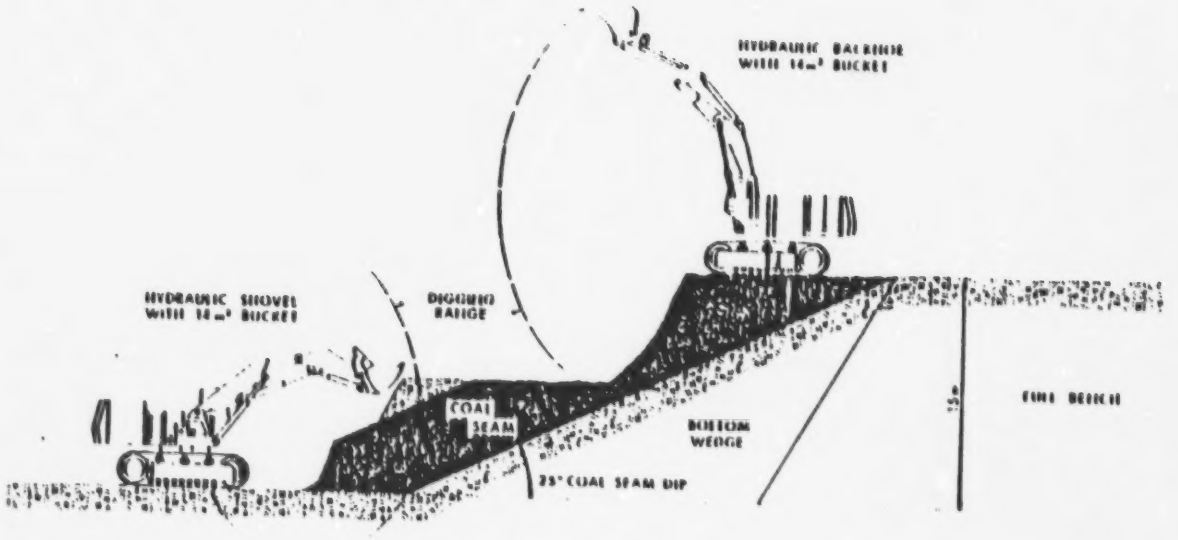


Figure 6. Range diagram of coal seam - digging by hydraulic shovel (Ref. 6)

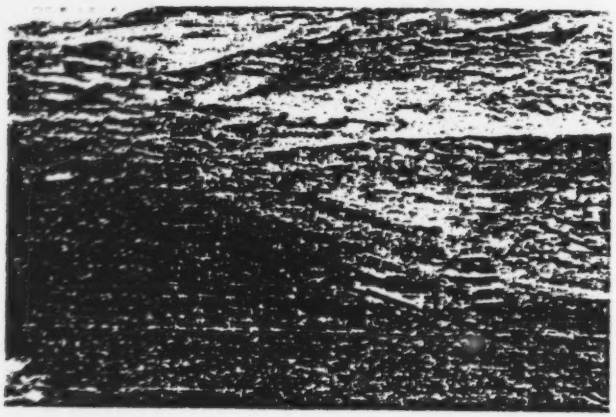


Figure 7. The footwall of a moderately dipping seam is being cleaned by the dozer.

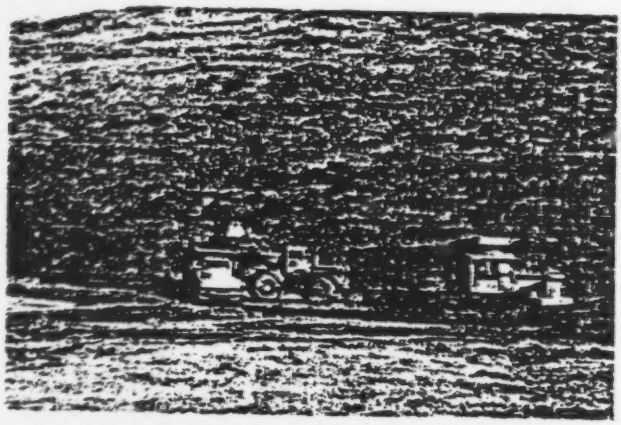


Figure 8. The coal dozed down is being loaded into trucks by a front-end loader.

Figure 10. The mountainous topography often necessitates

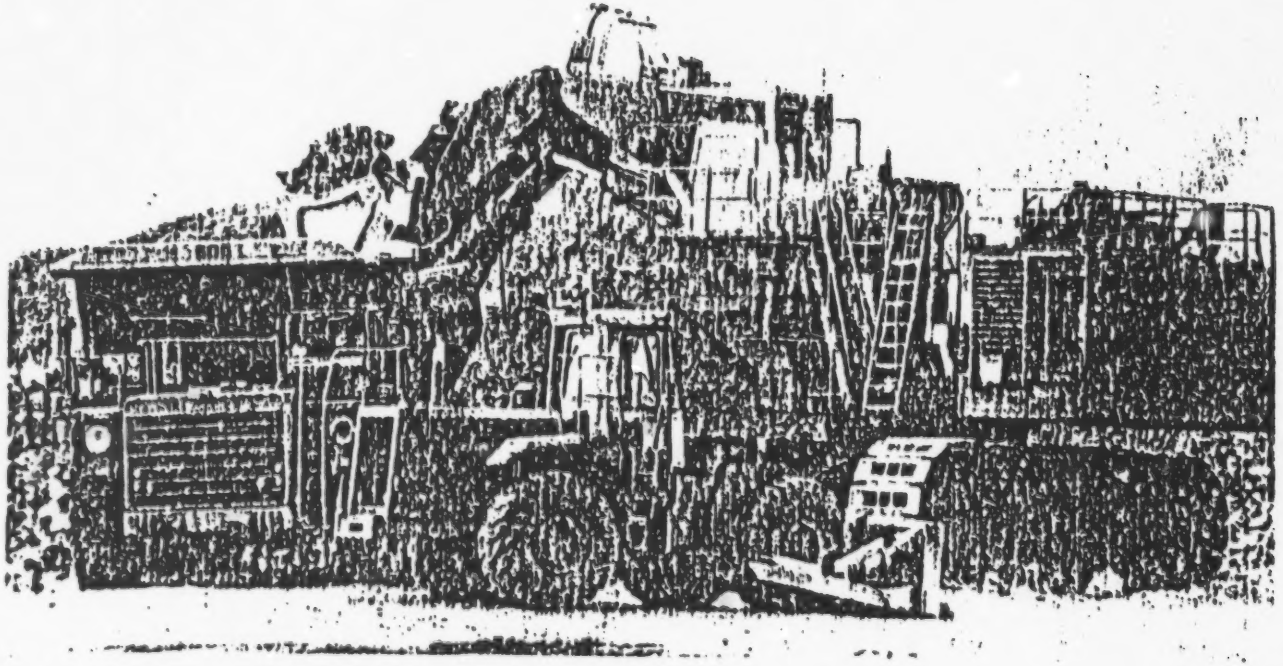


Figure 9. Demag H241 hydraulic shovel loading a Euclid R100 coal hauler.

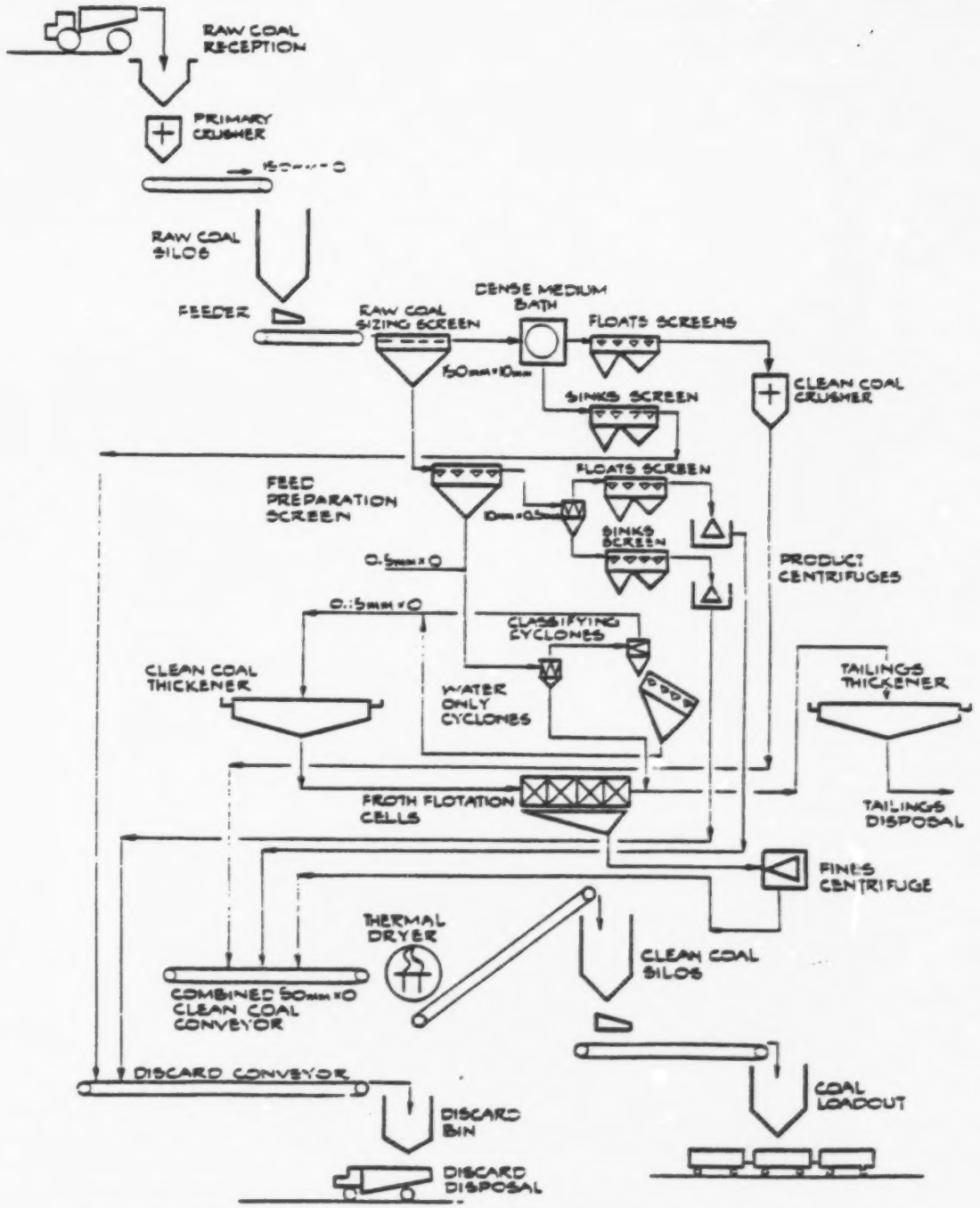


Figure 11. Example: Coal Preparation Plant flow sheet for Western Canadian coal.

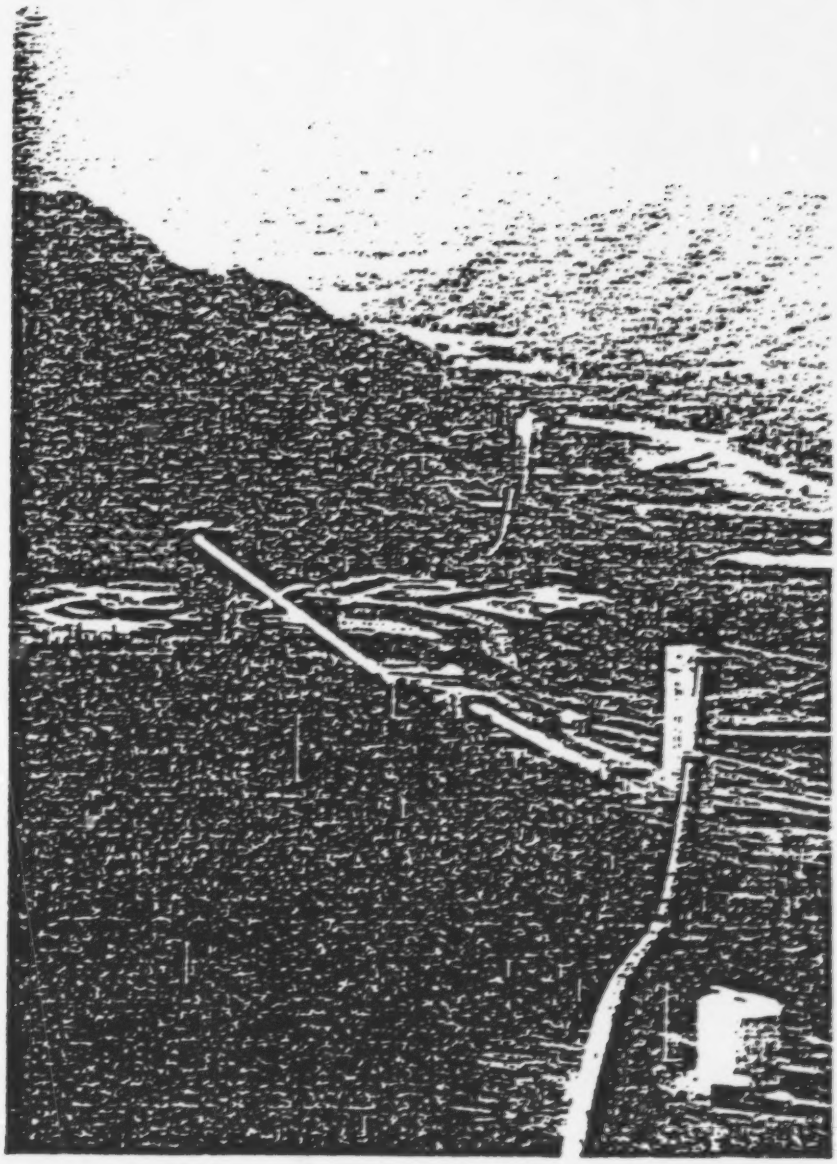


Figure 12. Belt conveyors are gaining rapid acceptance. This 5 km long system shown is at the Greenhills mine in British Columbia.

Figure 13. Mountainous topography places considerable constraints on mine planning. Picture shows the mountain view at Westar Mining's Greenhill Project. Sixteen coal seams are mined varying in thickness from 1.5 m to 10 m.

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PRODUCTIVITY AND EQUIPMENT SELECTION IN SURFACE MINING OF OIL SANDS

R.K. Singhal, R.J. Kolada and T.I. Vladut

Calgary Coal Research Laboratory

January 1986

For presentation at the SME - AIME Fall Meeting Albuquerque, New Mexico, October 16 - 18, 1985

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RÉSUMÉ

Un équipement minier varié est utilisé pour l'exploitation des sables pétrolifères à ciel ouvert. Cet équipement comprend les excavatrices à godets, les pelles à benne, les pelles hydrauliques et les camions hors-route. La présente communication examine les projets d'exploitation actuels et l'équipement utilisé. Les caractéristiques de l'exploitation des sables pétrolifères à ciel ouvert et leurs influences sur le choix de l'équipement et son utilisation de même que la planification minière sont aussi décrits dans cette communication. On y présente de plus les développements récents effectués dans le but d'améliorer la productivité des mines et quelques notes sur les mesures proposées pour obtenir une augmentation de la productivité.

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Abstract: A variety of mining equipment is used in the mining of oil sands by surface mining. This includes bucket wheel excavators, draglines, hydraulic shovels and off-highway trucks. This paper examines the existing mining schemes and equipment used Peculiarities of oil sands surface mining and their influence on equipment selection, utilization and mining schemes are described. Recent developments undertaken to improve mine productivity are also dealt with together with some notes on proposed measures to obtain further gains in productivity.

Introduction

Canada is a forerunner in the development of oil sands mining and processing technology. In this country, the first commercial plant to extract bitumen from the oil sands for processing to syncrude was installed in 1967 by Great Canadian Oil Sands Ltd. (now Suncor Inc.). The second commercial plant, managed by Syncrude Canada Ltd. came on stream in 1978. The combined full capacity of the two plants is approximately 200,000 bbls of syncrude per day. Both of these plants are located in the city of Fort McMurray in the province of Alberta. Alberta contains almost all of the Canadian oil sands deposits.

At the time of writing due to the trailing world wide economic recession and the glut on the world's oil market the work on the development of new oil sands projects has slowed down, none the less oil sands provide Canada with a tremendous energy source for the future.

The financial regime under which the existing oil sands plants operated, until very recently has also changed. The deregulation of oil prices effective June 1, 1985, reduced oil demand, and unrealised projected increase in the price of oil as forecast during the boom year of 1980-81 are all putting pressure on operating personnel to cut costs by increasing efficiency and productivity.

Mining Schemes

The bituminous sands which constitute the orebody at Suncor and Syncrude mine sites are contained within the McMurray Formation (Fig. 1). The average thickness of the bitumen saturated beds is 30 m but because of the highly irregular contact between the oil sand stratum and limestone base actual thickness varies from less than 5 to more than 85 m.

Bitumen concentrations average 11 to 12% by weight but range from less than 1% to 18%. Ore grading a minimum of 9% by weight is considered economic in the present day technical and financial regime. Ore averaging less than 6% is called "lean" and is usually stockpiled for future processing when appropriate technology or economics will allow viable extraction of the bitumen.

Production of synthetic crude oil from oil sands involves four basic operations: overburden removal, mining oil sands, extraction of bitumen from oil sands and upgrading the bitumen. This paper refers to the first two only by briefly reviewing the methods used to exploit oil sands.

Figure 2 shows the Syncrude's overall process of synthetic crude oil production from the oil sands. Overburden is excavated by hydraulic shovels and transported in off-highway trucks to disposal sites. Draglines excavate the oil sands which is stockpiled in windrows. The bucket wheel reclaimer-conveyor systems reclaim oil sands from this windrow and deliver to the extraction plant for processing. The oil sand is excavated by four draglines equipped with 60 m^3 buckets and 110 m booms. The highwall face angles range from 45° to 60°. The height of the bench varies between 40 m and 60 m. A single bench mining of oil sands is carried out (Fig. 3).

Unlike the Syncrude mine Suncor uses bucket wheel excavators in the excavation of overburden and oil sands (Fig. 4). Hydraulic shovels provide support in both of these areas but are primarily used for the excavation of muskeg and overburden.

Both of the oil sands plants use a variety of typical tire and track mounted auxiliary equipment.

Equipment Specifications

The mineral matter in the oil sands is 95 to 98% white quartz sand and as such they are very abrasive. During winter, in the Athabasca climate where temperature drop as low as -52°C, oil sands become extremely hard. During summer, when temperture can rise as high as 36°C the oil sands become soft and sticky.

Thus the nature of materials mined and the regional environment become major considerations when selecting mining equipment for an oil sands operation.

The size of the operation involved demands continuous mining systems of large capacity. The abrasive nature of the oil sands is extremely detrimental to the life of the cutting elements of mining equipment - crawlers, bearings, seals and other moving parts. Extreme hardness of oil sands during winter months demands that cold weather high strength steel be used on all load carrying members.

During winter months, frost is a serious problems which can be as deep as 5 m depending on the exposure time. In the fall before freezing temperatures occur the in-situ oil sand is fluffed up by drilling and blasting to reduce winter frost penetration and make excavation easier. Experience has shown that blasting of overburden improves the productivity of the bucket wheels and other equipment.

In oil sands mining winter and summer seasons are clearly identified 5 and 7 months respectively). Some activities are seasonal such as muskeg removal and dyke building for tailings pond which are accomplished better in one season than in another. On an average the production rate of a machine in oil sands during winter months is roughly 2/3 of its production rate during summer. Improvements to equipment, its application and operational procedures are being continually sought. Application of telescopic head-stations, hydraulically operated walking units for shiftable face conveyors, feeder breakers, computerized display and information gathering systems are a few examples.

Application of Mobile Equipment (Rubber Tired)

Trafficability in oil sands operations varies with the (1) nature of materials which behave differently in summer months than in winter due to changes in climatic environment; (2) site specific parameters relating to availability of suitable materials for road building - design, construction and maintenance of haulroads; (3) equipment type, size and its operative design.

The single most important factor influencing trafficability is the rolling resistance. In summer months, total resistance at a typical oil sands plant can exceed 20% of which approximately four-fifth (16%, is due to rolling resistance.

Reduction in rolling resistance will result in significant production/productivity gains for rubber tired vehicles. Lower rolling resistance will increase productivity requiring a smaller fleet to do a given job which in turn would mean lower capital investment in equipment fleet. Other benefits may also accrue due to reduced mechanical wear on trucks maintenance and fuel consumption etc.

In situations where roads are in good condition and have low rolling resistances the grade resistance can also have a significant effect on unit production rates. At the existing oil sands plants grade resistance, at present does not affect productivity as much as the rolling resistance. However, grade resistance may well become of increasing concern in the future as technological improvements in machinery and depleted reserves result in the extraction of ore from deeper levels. Non-availability of real estate may force building of waste dumps to higher levels resulting in steeper roads and greater grade resistance.

The soil types encountered in oil sands include peat-muskeg, sand-alluvial and lacustrine, gravel (alluvial), clay (lacustrine), clay (till) clay and sand (clearwater formation) and oil sands. Limestone formations underlie the oil sands. None of this material, except for some components of siltstones is a suitable material for haulroads. Load bearing capacity (LBC) of most of these materials is low. Permeability of is also low; some materials are practically impervious. As a result water does not drain easily and the haulroad surface remains "wet" making trafficability difficult. Silty materials totally breakdown in the presence of water becoming sludge. Swelling relating to wetted clay, in clay rich strata of low density, makes trafficability extremely difficult.

Measures for Productivity Enhancement

On the mining side the oil sands industry has become proficient in excavating and disposal of ore and overburden. Nearly twenty years of mining experience is now behind this industry. Many developments briefly described earlier were achieved gradually one step at a time. The technology and problems of today's oil sands projects are not the same as they were in the early 1970's. Interested readers are referred to a paper published by Allen (1973). The operating problems faced in those pioneering days are discussed in this paper. Since then oil sands excavation technology has come a long way.

At both oil sands operating plants (Syncrude and Suncor) considerable effort has been directed towards developing innovative technology, operating techniques and procedures for improving the productivity of mining operations. For example special rubber has been developed for belt conveyors to prevent them from cracking in a cold climate and when coated with bitumen. Newly developed corrugated rubber covered idlers have proved to be self-cleaning in operation eliminating the oil sand build up problems of steel shell idlers. A measurement and display system for the bucket wheel reclaimer (BWR) has been developed by Syncrude to improve the sustained output of the BWR - conveyor systems and to eliminate overloading which causes system trips and downtime. With the aid of this system the operator can continually forecast the total ore load on the long downstream conveyor. This information enables the operator to control the BWRs digging rate to optimally load the conveyors according to the prevailing operating conditions.

Several positive developments have materialized in the design of bucket wheel cutting teeth, their geometry and metallurgy. In case of draglines changes have been made to the original bucket and tooth design. The development and adaptation of dynamic stress measurement techniques has permitted improvements in structural and mechanical design of components such as boom rope socket design and boom, tub and revolving frames etc. A recent addition to the mining schemes has been a feeder breaker. A test program with a feeder breaker was carried out by Syncrude from 1982 to 1984. Many changes were required to the original test machine in the breaker shaft, pick configuration, drive arrangements and power for both breaker and feed conveyor. A production machine was commissioned by Syncrude in December 1984. The general arrangement of the scheme incorporating the feeder breaker and the truck discharged ore is shown in Fig. (5). Suncor also has feeder breakers on order.

Modifications have also been made to the Demag H241 hydraulic loading shovels. Buckets have been reinforced against abrasion with Sheritt Gordon studs instead of hard surfacing; oil sand wedges between the studs and thus becomes the wear surface. Hydraulics have been modified for a range from 40° to -70°C to provide increased cooling capacity in summer. Large diameter drive sprockets were installed to cope with elongation of the truck pad due to swing action. Reducing operating power to 1000 kw from the rated 1200 kw has contributed to less wear. Track pads on shovels are being increased to 3 m in width to maintain ground bearing pressure at 170 kPa maximum.

The 170 ton Titans have been modified to adapt the electric drives to oil sands operation, so that they switch from parallel to series when dumping with 30% rolling resistance. A large axle developed to cope with the torque is twice the size of the original.

General Discussion on Proposed Measures for Productivity Enhancement

High capacity equipment is used for excavation of overburden and ore in the two operating oil sands plants - be it either a dragline or a bucket wheel excavator. Each bench or quadrant is equipped with its own independent material handling systems.

It is considered that a variety of mining equipment is now available to form components of continuous mining systems. Equipment sizing is just as important as the selection of the type of equipment and a mining method. For every mining operation depending on its production rate, haul distances and geology of the deposit there is an optimum size of equipment. Studies carried out elsewhere and based on the analysis of actual data from operations nearly similar in size as the operating oil sands plants, suggest that in terms of equipment sizing "bigger the better" is often not true. A medium sizedequipment might be more economical particularly when ore of varying grades and quality is to be mined from more than one working face and where storage capacity is limited. For new surface mineable oil sands projects which may be of a size smaller than the two currently operating consideration will be given to mid size equipment. In case of bucket wheels an example of this type of equipment is the all hydraulic bucket wheel excavator. Capital cost of these machines is low; delivery time shorter and their output up to 2000 bank m^3/hr.

In terms of draglines, there is seemingly a growing consensus that when sizing a dragline an allowance must be made for an unanticipated increase in depth particularly where highwall stability is a problem. This, in turn, generally calls for an allowance in the sized length of the dragline boom. Once a dragline has been purchased boom length cannot be changed easily. In general, for material depth of up to 30 m a single pass dragline is adequate and economical; for depths between 30 m and 45 m a dragline with longer boom or tandem draglines systems should be considered. At depths of 45 to 60 m a single dragline is not competitive with other systems and a pre-stripping system should be considered to support it.

Draglines are designed to dig below the surface and their use in chop cutting should be avoided. Chop cutting always results in reduced productivity sometimes by as much as 50% compared with the normal operating mode of a dragline.

For overburden handling Syncrude utilizes a fleet of hydraulic shovels/trucks. The hydraulic shovels are Demag H-241s with 19 cu.yd. capacity matched to Titan 33-15B, 170 t diesel electric trucks. By contrast Suncor are replacing their 150 t/170 t diesel electric truck fleet with smaller mechanical drive 85 t trucks. It is clear that a variety of technical and non-technical site specific parameters have played a role in these decisions. Suffice to say that an assortment of continuous mining equipment for excavating, loading, transportation and disposal of materials (based on conveyor utilization) is available in many sizes and might be considered.

One new component which deserves oil sands industry attention is the high angle conveyor (HAC) for lifting the material from the pit. Such conveyors have been designed by more than one manufacturer. The first production unit in the world is in use at the Triton Coal's mine in Wyoming. HAC conveyors can be mounted either on rails, rubber tires or crawler type transporters or equipped with walking mechanisms for optimum mobility.

The HACs are highly energy and cost efficient - they can lift material to greater height over short distances and utilize much of the energy in elevating the materials. Trucks have to deliver their payload plus their own dead load which can range upto 45% of total gross hauled weight.

Trucks provide the flexibility required in a surface mine and can operate in confined spaces. For this reason, in spite the availability of a variety of conveyors trucks would continue to be used in surface mining of oil sands. Their productivity is greatly dependent on the haulroad condition. Poorly maintained roads and roads surfaced by weak materials lead to an increase in rolling resistance and poor trafficability. Good trafficability on mine roads will be achieved by properly designed and constructed haulroads. Bitumen based emulsions, cement, calcium chloride, lignosulphates and hydrated lime are a few examples of road surfacing materials that may be used.

As described in oil sands operations not many naturally occuring soil materials can provide a stable road base commensurate with the duty imposed on them by the size and weight of the trucks and other mobile equipment. However, the load bearing capacity of such materials can be improved by application of soil binders resulting in reduced rolling resistances. Some unconsolidated soils can be transformed to a degree of stability such that it will accommodate the weight of some vehicles. In some cases application of binders will result in significant reduction of the quantity of base material required in road construction whereas in others binders mixed with subgrade soils can be used directly as a road surfacing material. Several types of binders are available for application on surface haulroads. It is known that some stabilizing procedures have already been used on oil sands operations. These include use of lime and sulphur additives; however reportedly they have not proved effective. More research is needed in this area.

Concluding Remarks

In surface mining a very large part of capital and operating costs is consumed in the material handling phase of the operation. Oil sands mining is no exception. Therefore efforts are being made in the pit, in the mine design and planning phase to develop alternatives to improve cash flow, and in developing programs to improve the life, reliability and flexibility of existing equipment and systems and to improve upon their performance. New technology which will reduce material handling costs is being investigated e.g. computerized truck dispatching, hydraulic transportation, dredging etc. Micro-processor based real time data collection and analytic systems are being installed on individual pieces of equipment which can

transmit to a central control station.

Canadian oils sands mining industry has made phenomenal progress during the past decade and has established itself as a technical leader for high volume mining and materials handling of a difficult material in a hostile climate. In spite of this level of achievement work continues towards improving the existing technology.

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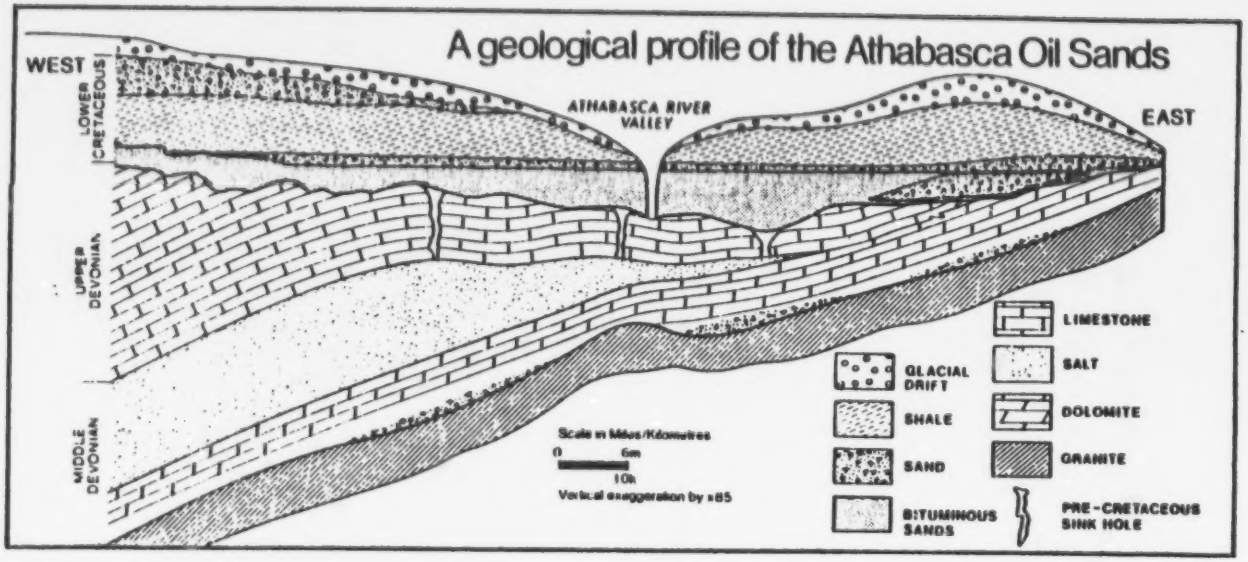

Figure 1. A geological profile of the Athabasca oil sands

SYNCRUDE'S OVERALL PROCESS

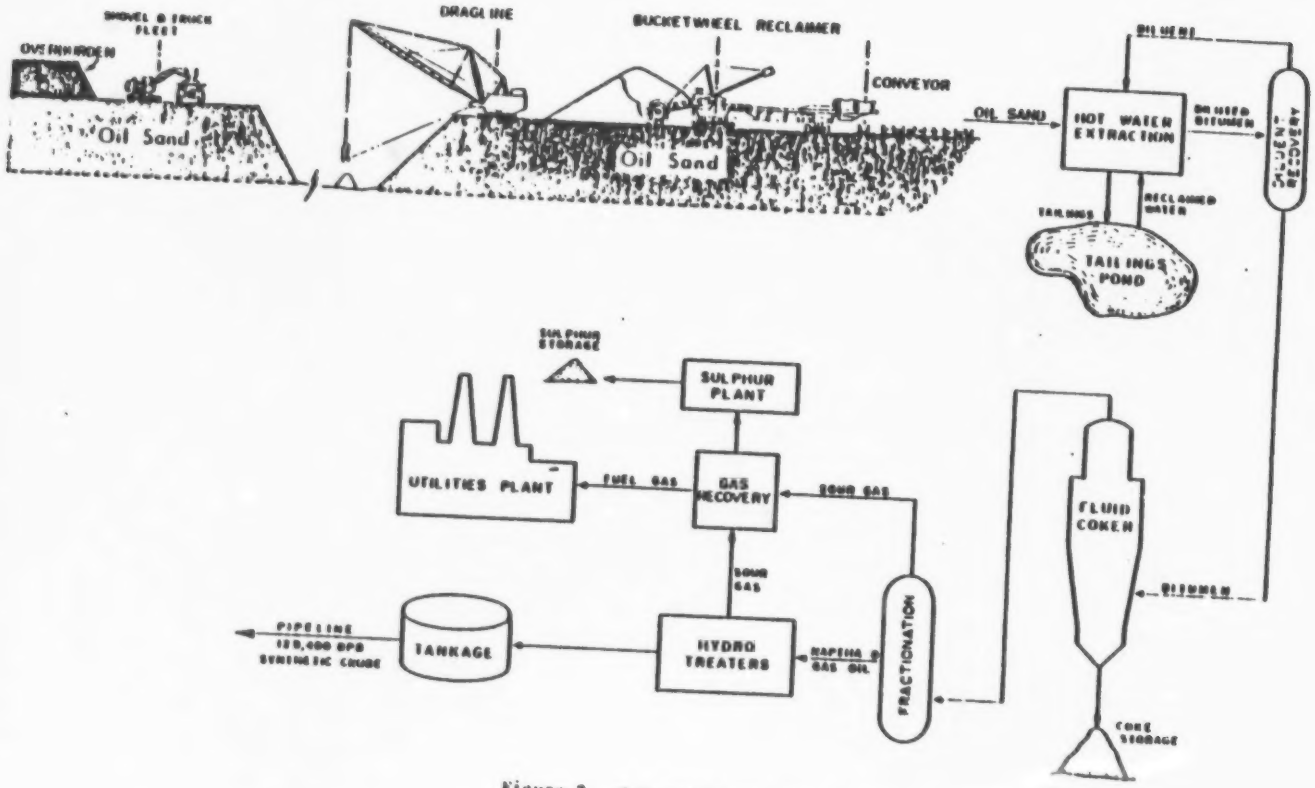

Figure 2. Syncrude's overall process

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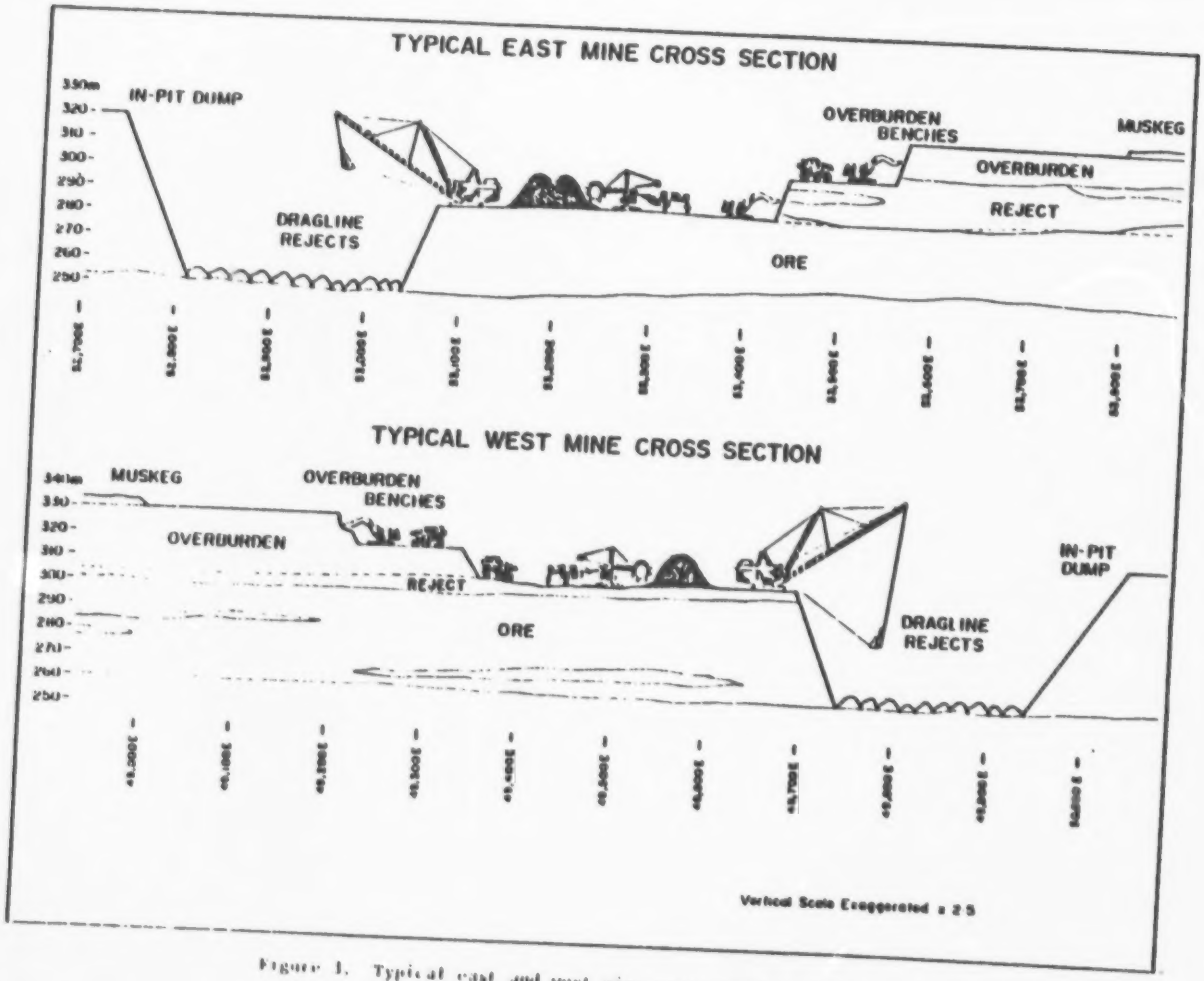

Figure 1. Typical east and west mine cross section at Syncrude

Figure 4. Bucket-wheel excavator's at Suncor's oil sands operation

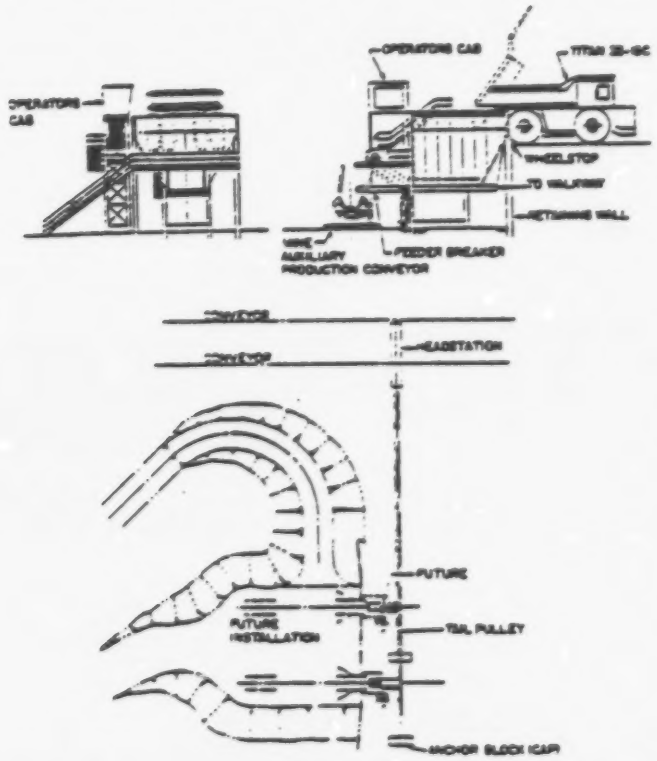

Figure 5. Application of feeder breaker in auxiliary oil sands production arrangement at Syncrude (Courtesy D. Adams and Syncrude Canada Ltd.)